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Astronomical Fiction

From time to time books are issued in which astronomical facts and theories are made the starting point for excursions into domains in which the imagination is given free range. Depending upon the scientific background possessed by the writer, such books are in some instances quite clever and in others utterly fantastic. Again depending upon the scientific maturity of the reader, such books are in some cases greatly enjoyed, in some other cases entirely discredited, and in still some others are assigned an importance far in excess of their merits. However, as long as a book and a number of isolated readers are concerned, no cumulative effect is created and no concerted movement results.

However, when a broadcast replaces the book and hundreds or thousands of hearers replace the isolated reader, a very different situation is engendered. If a record of the panic which seized large numbers of the American people as a result of a misunderstood broadcast in the latter part of the year 1938 is preserved for the future, coming generations may have difficulty in reconciling such a phenomenon with the level of intelligence characteristic of the present. In spite of the numerous physical impossibilities involved, and clearly implied in astronomical science, an unknown, though apparently a very large, number of persons believed that monsters with the most malevolent purposes had actually arrived on the earth from Mars.

There is a legend related to the so-called Delian problem, or the problem of duplicating a cube, as follows: In order that a very destructive plague in Athens might be stayed, the oracle on the island of Delos was consulted. The requirement imposed was that the altar of Apollo be doubled in size retaining, however, its cubical shape. This at first seemed simple but was ultimately found to be incapable of solution in terms of the geometrical principles known at that time. The assistance of the wisest men of Athens was sought. They too were baffled by the difficulty of the problem. As a result of their discomfiture the Athenians came to the conclusion that evidently the gods wished them to study *geometry*.

Similarly as a result of the experience we, as a people, had in connection with the broadcast referred to above, we may reasonably infer that evidently the gods wish us to study *astronomy*.

If the somewhat hypothetical Martians are as intelligent concerning the earth and the people on it as is indicated by ascribing to them the ability to board an earth-bound meteorite, and if they are not entirely devoid of humor, they must have had a most hilarious hour from eight to nine P.M., E.S.T., October thirtieth, nineteen hundred thirty-eight.

William Wallace Campbell
1862-1938

By FRANK SCHLESINGER

When William Wallace Campbell quit the Lick Observatory in 1923 to become president of the University of California, one of the most eminent observers of the century and one of the most able of leaders was lost to astronomical science.

Campbell was born on a farm in Hancock County, Ohio, on April 11, 1862, the son of Robert Wilson and Harriet (Welch) Campbell. At the age of twenty-four he was graduated at the University of Michigan, then, as for many years before and after, the cradle of distinguished astronomers. In those days the opportunities for graduate study in science were rare in this country. I believe that Benjamin Gould and William Elkin were the only astronomers older than Campbell who went on to the Ph.D. degree, and both of them got this training in Europe. Immediately after being graduated B.S., Campbell received and accepted an offer of a professorship of Mathematics at the University of Colorado. Here he remained for two years, returning in 1888 to the University of Michigan as instructor in Astronomy. Three years later he eagerly accepted an offer to become one of the astronomers at the recently (1888) organized Lick Observatory. Director Holden knew how to select men; in the few years that he was in charge of the Lick Observatory he had gathered on Mount Hamilton such astronomers as Burnham, Barnard, Keeler, Schaeberle, Crew, Aitken, Campbell, Hussey, and Wright, a band which for ability and productiveness would have been hard to match at any other observatory here or abroad.

Campbell's chief work at the Lick Observatory was, as everyone knows, the determination of velocities in the line of sight. Keeler, who was on the original staff, had made a good beginning in such work in determining by visual methods the velocities of fourteen gaseous nebulae; but his work was soon interrupted by his acceptance of the directorship of the Allegheny Observatory in 1893. This left the field of radial velocities open to Campbell, who adopted the photographic method and who soon set an astonishingly high standard for precision. With a three-prism spectrograph he was able to determine the velocity with as low a probable error as one-quarter of a kilometer for a single plate in the case of those stars with lines sharp enough and numerous enough for the best results. This precision has never been surpassed by any of Campbell's successors in the forty years that have since elapsed. It was due to a high order of skill and experience, combined with a patient watchfulness over the minutest details.

In 1898 Holden resigned the directorship of the Observatory and Keeler was recalled to Mount Hamilton to take his place. Soon after his

appointment he gathered the staff around him in the library of the observatory and made a statement of his policy, terminating with the avowed intention of devoting his own energies to the newly-acquired Crossley reflector. (Several members of the staff had attempted in vain to do useful work with this reflector. Keeler's great success in the photography of nebulae with it, in the two short years that were left to him form a stirring chapter in the history of astronomy.) This decision must have been a great relief to many of the members of the staff and to none more than to Campbell, for it would have been only natural that Keeler should elect to go on with his work with the spectrograph, work that he had pursued to such good purpose both at Lick and afterwards at Allegheny Observatory.

Keeler's life was undoubtedly shortened by his coming to Mount Hamilton. He was affected by a weak heart without being aware of it. This complaint was aggravated by the fact that he lived on one of the peaks at Mount Hamilton and worked upon the other, an arrangement that necessitated considerable hill climbing. He was suddenly stricken in the summer of 1900 and died within a few weeks. President Wheeler of the University of California wrote to a selected list of twelve prominent astronomers, both on this and on the other side of the water, asking for nominations for the directorship. All twelve without exception named Campbell, who was appointed in 1901 and remained director nominally until 1930, but actually until 1923 when he accepted the presidency of the University.

The determination of radial velocities soon became the leading activity of the Observatory and indeed constituted probably the most important observational program going on anywhere during the first two decades of its progress. In this work Campbell had the collaboration of many members of the staff particularly of W. H. Wright and of J. H. Moore. In 1903 when the Carnegie Institution of Washington was organized, a substantial annual subvention in aid of the work was among the first grants to be made, and was continued for a long term of years. The principal object was the determination of the sun's way and speed in space. From the Lick Observatory only about three-quarters of the sky can be well observed, and this, as Campbell said, was like trying to fly with one wing; for the best results it was necessary to cover the whole sky, and this meant the establishment of a southern station. In 1903 Campbell succeeded in interesting D. O. Mills in this project and with his aid (and afterwards that of his son, Ogden Mills) a reflecting telescope with a suitable spectrograph was set up and maintained near Santiago in Chile in southern latitude 33°. This expedition was at first attended by ill luck. When the Crossley reflector was acquired by the Lick Observatory the gift included a second mirror of 36-inches aperture; it was planned to use this duplicate for the southern telescope. But it did not have the central hole so desirable when a mirror is used in the Cassegrain form, a form that is all but essential for spectrographic work. It

was decided to bore a hole in the finished glass, about five inches thick. The danger of releasing in this way internal strains and of shattering the mirror was well understood and proper precautions were taken against such an explosion and the consequent danger to the optician; it was fortunate indeed that these precautions were taken, for the glass broke into thousands of pieces. Fortunately no one was hurt and the worst consequence was the delay; but a new glass was soon secured and figured. Again, when the mounting was completed, Campbell decided to set it up in California before taking it south. In doing so a mishap caused Campbell to strain his back, the first serious indisposition from which he had ever suffered. As a consequence he himself was prevented from taking the completed instrument south as he had intended; this task devolved upon young Wright, who carried it out with great success.

In addition to the determination of the sun's way, the work of these two spectrographs was full of interesting by-products. Chief among these was the discovery of a surprisingly large number of spectroscopic binaries. Among B-type stars one in three proved to be double, with somewhat smaller ratios for stars of advanced type. When the question of changes in periods of these binaries comes to be studied, these early observations will be found invaluable, for they precede by at least a decade accurate observations at any other observatory. In the case of some southern binaries these are still the only observations that exist.

Campbell's work did not stop with the determination of stellar velocities; it in fact covered nearly the whole field of spectroscopic investigation so far as this had been developed in his day. Especially notable was his success with total solar eclipses. His good fortune with regard to the weather at these rare events came to be known as "Campbell luck." The plates he secured form the basis of an elaborate discussion by D. H. Menzel in one of the volumes of the Lick Publications. The last eclipse in which he took active part was that in Australia in 1922. There he and R. Trumpler confirmed beyond reasonable doubt the reality of the Einstein deflection of stars at the limb of the sun.

It was when he returned to San Francisco after this eclipse that he was met at the pier by one of the members of the Board of Regents of the University of California with an offer of the presidency of the University. He had long ago resolved to devote himself unreservedly to astronomy, and had earlier refused at least one equally attractive offer to become the head of an academic institution; so that he declined this offer without hesitation. But when the plea for his acceptance was put upon personal grounds and when the pressing necessity for his service was made clear to him he felt he had no alternative but to accept. He was then (1923) in his sixty-second year, yet he hoped to return to the Lick Observatory after he should have served a few years as president. For this reason he retained the nominal directorship; but, as all his friends foresaw, he was never able to realize this ambition and when in 1930 he retired from the presidency he relinquished the directorship as

well, to be succeeded in this office by R. G. Aitken.

Ill health had been all but unknown to him until his sixty-ninth year; thereafter he hardly knew what it was to be well. A complication of complaints led to loss of sight in one eye and the serious impairment of the other. Believing that total blindness was in store for him and unwilling to become a burden to his devoted wife, he died by his own hand on June 14, 1938.

The keynote of Campbell's success in life was his sterling character. He was a man of quick decision and he stood firmly by a decision once made. Fairness in all his dealings was a conspicuous trait. These characteristics are essential to a successful director of a mountain observatory like the Lick, where a dozen families are dependent upon the Dirctor not only for guidance in matters scientific but in matters domestic as well, such as how to house the various members of the staff both married and unmarried, to what "mess" to assign them for their meals, and so on. Whatever his method was there is no denying its high results, for the Lick Observatory during his administration rose to the pinnacle of productiveness that made it universally recognized in its day as the leading observatory of the world.

NOVEMBER 30, 1938

Theoretical Problems of Stellar Absorption Lines

By DONALD H. MENZEL

Introduction

Progress in interpreting stellar spectra has from the beginning paralleled progress in atomic physics. Any advance in one field has usually produced a corresponding advance in the other. In both physical and astrophysical problems, observation has generally led the way with theory following close behind.

The early stages of stellar spectroscopy were, of course, largely qualitative in character. The measurement of wave-lengths was about the only quantitative feature of the early researches. The applications of the wave-length measures were only qualitative. Early investigators were satisfied merely to list a few of the various chemical elements present in stellar atmospheres, without any reference to the abundances or ultimate chemical compositions.

As we look back upon the beginnings of modern astrophysics, we find it difficult to fix the exact moment of transition from the qualitative to the quantitative stage. Did it occur when Lockyer recognized the existence of "proto" atoms, which we now refer to as "ionized" atoms? Should one give to Saha the credit for starting quantitative work, when he applied the chemical dissociation formula to stellar atmospheres? Or perhaps the credit should go to Unsöld, who, following John Q. Stewart, used semi-classical formulae for absorption coefficients to analyze the observed profiles of absorption lines.

I could easily name a score of major contributions by almost as many contributors. Among them are: H. H. Plaskett, with his interpretation of the spectra of three O-type stars; Fowler and Milne, Pannekoek, and Russell for theoretical discussions of absorption-line intensities with particular reference to variations along the spectral sequence; Eddington, Milne, Pannekoek, and B. Strömgren, who treated problems of line profiles; Minnaert and Slob for observational data on the solar spectrum and the interpretation of the curve of growth; Struve for quantitative observations of stellar absorption lines, investigations of curve-of-growth phenomena, the Stark effect, turbulence, etc.; Russell with his first serious attempt at quantitative analysis; Allen for his monumental studies of equivalent widths in the solar spectrum; etc. . . . .

The foregoing list is still far from complete as to investigators, but it is fairly representative of the type of work that has been carried on with increasing momentum during the past fifteen years or so. As one views the work, in retrospect, he can see definite signs of progress. The crying need for quantitative observational data is gradually being fulfilled. Measures of absorption-line intensities in the ultra-violet and

infra-red portions of the spectrum are wanted, as are further measures of equivalent widths in all classes of stellar spectra. The making of such measures is a problem in itself, and I shall not attempt to discuss it here, except to say that the systematic differences between determinations by independent observers are all too large. Greater care must be taken in the elimination of scattered light and in the determination of characteristic curves of the photographic plates.

The problem of predicting theoretically the intensities of lines in the spectrum of a star is extremely intricate. The problem may be partially sub-divided from the physical point of view, but the various phases so overlap that complete separation is impossible. I have prepared the following list of topics in the order of consideration.

1. Line absorption
2. General absorption
3. Atmospheric models
4. Transfer of radiation
5. The stellar continuum
6. Profiles of absorption lines
7. Curves of Growth
8. Maxima of spectral lines as a function of temperature and pressure
9. Chemical composition
10. Miscellaneous difficulties and outstanding problems.

In the present paper less emphasis than usual will be laid on the mathematical phases of the problem. Simultaneously, every effort will be made to explain the physical processes operative in stellar atmospheres. For convenience of reference, various fundamental equations are given.

(1) *Line Absorption.* On the basis of the old classical electromagnetic theory, the atoms were supposed to contain electrons that were capable of sustaining oscillations of a perfectly definite frequency. Like a stretched piano wire, the electrons, when set in vibration, were believed to emit a train of waves. The wire transmits its vibrations to the atmosphere and continuously loses energy in the process, which is to say that the vibrations are "damped." For the atom, the "ether" was supposed to receive and transmit the oscillations, in the form of electromagnetic (light) instead of sound waves. The "damping" is also electromagnetic in character; the amplitude of the electron oscillations dwindles as energy is lost to the ether.

The trains of light waves thus emitted by a classical atom are finite in length. They begin at the moment of excitation and decay exponentially thereafter. In nature there is no such entity as a strictly monochromatic line. Theoretically, a pure frequency could be emitted only by an atom that has been vibrating with strictly constant amplitude for an infinite length of time. Even then, such an atom could not emit radia-

tion because its behavior implies no damping or loss of energy. Whenever damping of any variety is present, even if the peaks of the successively emitted waves are evenly spaced, and even if the peaks of a finite train are of the same amplitude, analysis shows the presence of frequencies other than the fundamental. The spectroscope, quite apart from instrumental resolving power, will show the line to be of finite width. (Figure 1.)

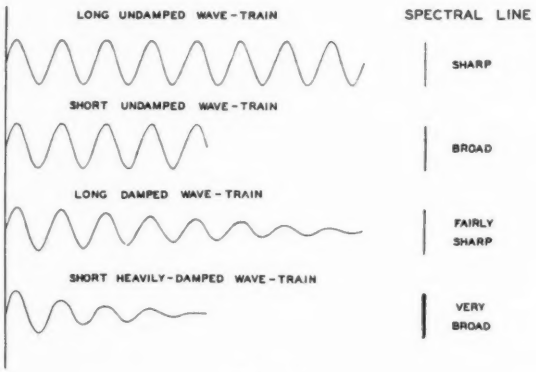


FIGURE 1

According to classical theory, a single atomic oscillator, exposed to a beam of radiation of frequency ν, will behave like an opaque absorbing sphere, of cross-section $a(\nu)$, defined by:

$$a(\nu) = \frac{8\pi\epsilon^4}{3m^2c^4} \frac{\nu^4}{(\nu_0^2 - \nu^2)^2 + (\gamma\nu/2\pi)^2}. \tag{1}$$

where γ is the so-called classical damping factor

$$\gamma = \frac{8\pi^2\epsilon^2\nu^2}{3mc^3}. \tag{2}$$

$a(\nu)$ is called the atomic absorption coefficient. ϵ and m refer to the electron charge and mass, respectively, c to the velocity of light, and ν_0 to the natural vibration frequency of the oscillator. Equation (1) is of great physical importance and several approximate expressions may be derived from it. In the neighborhood of the line, $\nu \sim \nu_0$, and

$$a(\nu) = \frac{2\pi\epsilon^4}{3m^2c^4} \frac{\nu^2}{(\nu_0 - \nu)^2 + (\gamma/4\pi)^2} = \frac{\pi\epsilon^2}{mc} \frac{\gamma}{4\pi^2} \frac{1}{(\nu - \nu_0)^2 + (\gamma/4\pi)^2}. \tag{3}$$

An oscillator loses energy according to the equation

$$E = E_0 e^{-\gamma t}, \tag{4}$$

where E_0 is the initial energy and E the energy at any time t. The finiteness of γ keeps the train from being purely monochromatic. The

more nearly the ideal condition of an infinite, ideal train is approached, the sharper and narrower will be the emitted spectral line, as equation (1) shows. An atom that has a high probability of emitting its energy in a given interval, *i.e.*, one that emits a very short wave train (γ large) will produce a very broad line. It has been suggested that the great breadth of lines in the solar corona may be due to an effect of this sort. Similarly, the intrinsic breadth of a line from an atom that takes a very long time to radiate its energy, *e.g.*, an atom emitting one of the nebular lines, will be extremely small. Any physical condition that tends to disturb the normal radiating conditions of the atom will tend to broaden the line still further. Collisions of radiating atoms with other atoms or with electrons interrupt the wave train and give rise to broadening effects termed "collision damping" as opposed to "radiation damping." In consequence of the greater atomic interactions, spectral lines emitted by a dense gas are generally broader than the lines emitted by a rarefied gas. (Figure 2.)

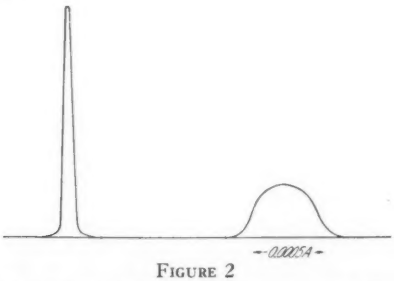


FIGURE 2

PROFILES OF EMISSION LINES FROM SINGLE ATOMS.
Left, with radiation damping only; right, with collision damping.
Note that the areas (total intensities) are about equal.

An actual atom, of course, does not radiate or absorb like a classical oscillator. There is, nevertheless, a correspondence between the two. Wave-mechanical calculations of atomic transitions between two levels reveal sinusoidal surges of electric charge between the initial and final configurations. The formula for the absorption coefficient close to the line is similar to that of equation (3). We have merely to replace the classical damping factor by the quantum-mechanical damping factor, Γ, and to multiply the right-hand expression by a dimensionless constant, f, characteristic of the atomic transition involved. The absorption coefficient thus defined may be integrated over all frequencies, to give the total absorption per unit intensity of illumination. Thus

$$\int_0^\infty a(\nu)\,d\nu = (\pi e^2/mc)\,f, \tag{5}$$

f times the classical value.

The curves of Figure 2 represent the profiles of the radiation sent out

by a single emitting atom. The line produced by an assembly of atoms may have an entirely different appearance. Each atom will radiate individually, as described above, but the radiations will be shifted to the violet or red, according to the motion of the emitting atom toward or away from the observer. (Figure 3.) The resulting emission line is

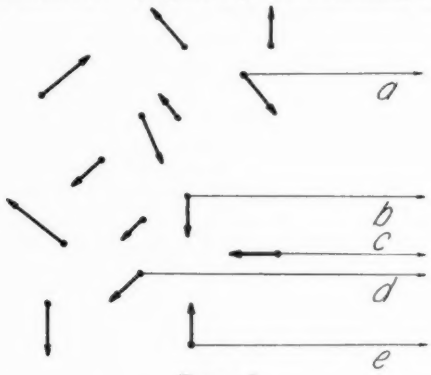


FIGURE 3

Heavy arrows indicate directions and magnitudes of motions of individual atoms. The motions are at random. An observer from above would find, as result of Doppler effect, the emitted light from atom *a* displaced to violet, from *c* and *d* displaced to red, and from *b* and *e* essentially undisplaced.

greatly broadened in consequence of the Doppler effect. The profile of such a line is shown schematically in Figure 4. Note the steepness of

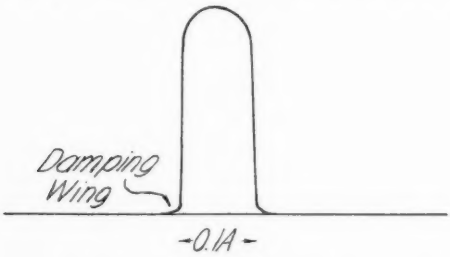


FIGURE 4

PROFILE OF EMISSION LINE, WITH DOPPLER EFFECT INCLUDED.

The horizontal scale has been contracted and the vertical one extended from those of Figure 2, by a factor of about 400 times. The indicated broadening is for hydrogen at the solar temperature.

the shoulders. The extensions of the profiles in the far wings are shown with highly exaggerated intensities. These extensions arise from the damping effects described in the previous paragraph.

The general expression for the atomic absorption coefficient,

$(\nu \sim \nu_0)$, which includes the effect of Doppler motion, may be written:

$$\alpha(\nu) = \frac{\pi e^2}{mc} f \left[\frac{c}{\pi^{1/2} v \nu_0} e^{-[c(\nu - \nu_0)/v\nu_0]^2} + \frac{\Gamma}{4\pi^2} \frac{1}{(\nu - \nu_0)^2} \right], \quad (6)$$

where v is the "most probable" atomic velocity, given by

$$v = \sqrt{2kT/m_a} \quad (7)$$

for the gas-kinetic motion, k is Boltzmann's constant, T the temperature, and m_a the atomic mass. The first term in the brackets of (6) is to be used near the line center and the second term disregarded until its value, somewhere in the wings, becomes appreciable compared with that of the exponentially decreasing first term. Only the first term should be used in checking the integral (5). As Struve has pointed out, we may conceivably find, in certain stars, turbulent motions in excess of the gas-kinetic. Under such circumstances, if the motions are at random along a given line of sight, we may still employ the parameter v to represent the mean turbulent velocities.

There is at least one other source of a line broadening that sometimes makes itself felt in stellar lines, viz., electric fields, or Stark effect. The fields may be macroscopic, as in a laboratory discharge, or microscopic, as produced by the proximity of a charged ion or electron to a neighboring atom. It is generally believed that part, at least, of the great breadth of the hydrogen lines in stellar spectra is due to the mol-electric broadening, as the microscopic Stark effect is sometimes termed. The great breadths of certain lines of helium, and the occurrence of some spectral lines (also of helium) that vanish except when a strong electric field is present, are also attributed, by Struve, to the occurrence of mol-electric fields.

Knowledge of the theoretical intensities of spectral lines is of importance in interpreting spectra. The atomic transitions that give rise to certain lines of a given atom may originate in the same energy level. The well-known yellow D-lines of sodium, for example, have the same initial lower atomic level and different (though neighboring) higher atomic levels. (Figure 5.) The two lines are not of equal intensity, however. Under the simplest physical conditions, where a minimum of self-reversal exists, the line of shorter wave-length has about twice the intensity of the other line. The theoretical intensity of the line is indicated quantitatively by the value of f. The evaluation of f, numerically, is a wave-mechanical problem of great complexity, which has been solved exactly only for atoms having one free external electron, viz., hydrogen and ionized helium. Approximate solutions have been obtained for neutral helium and for certain lines of other more complex atoms.

It is well known that analysis of the laboratory spectra of various atoms has enabled theorists to segregate the spectral lines of a given atom into groups or families. The pair of D-lines of sodium form a "doublet." Other lines of more complicated examples may be selected to form what

are generally termed "multiplets." Certain of the multiplets, in turn, may be gathered into groups. For lines belonging to these supergroups, the most comprehensive of which is called a "transition array," the theoretical intensities of the individual lines may be fixed on a relative, though not always on an absolute, scale.

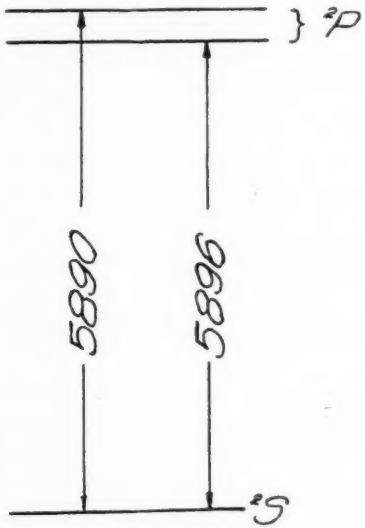


FIGURE 5

SCHEMATIC DIAGRAM OF SODIUM LEVELS INVOLVED IN PRODUCING THE D-LINES.

The theoretical intensities, the f's referred to above, are supposed to be atomic constants, irrespective of the external physical conditions.* They are evaluated on the condition that one atom or any specified number of atoms be found in the initial atomic level. Then the intensity of the absorption or emission lines will be fixed. In practice, however, the relative numbers of atoms to be found in various atomic levels will depend markedly upon the physical state of the gaseous assembly. Lines from high atomic levels will generally be weaker at the lower temperatures.

The relative number of atoms in the upper and lower levels, of weights $\tilde{\omega}_1$ and $\tilde{\omega}_2$ and energies E_1 and E_2, are given by the Boltzmann formula,

$$\frac{N_2}{N_1} = \frac{\tilde{\omega}_2}{\tilde{\omega}_1} e^{-(E_2-E_1)/kT} , \qquad (8)$$

*This assumption is not quite true, as electric fields will alter the value to some extent.

for an assembly of gas in thermodynamic equilibrium. Equation (8) will hold explicitly only for matter in an insulated enclosure, where each atomic transition is exactly balanced by its reverse. Obviously, a stellar atmosphere, through which energy is streaming, is far from being in thermodynamic equilibrium. We should not be surprised to find marked deviations from Boltzmann's law. To calculate the ratio, N_2/N_1, theoretically, requires detailed knowledge of the possible atomic processes that may remove atoms from or put atoms into one or the other of the two levels under consideration. No longer can we expect detailed balancing of individual processes. We must consider all possible atomic transitions in the assembly, which requires, in turn, knowledge of the radiation field.

(2) *General Absorption.* The atoms of a stellar atmosphere serve to dam back the radiation in the lines. By analogy we infer that the atoms must also present some opacity to radiation in the continuum between the lines. The cross-section presented by an individual atom to the radiation continuum is called the atomic coefficient of general absorption.

Continuous absorption may arise in a variety of ways. Several possibilities are indicated as special cases of the classical formula (1). Although most of the absorption occurs very close to the line centers, a not inappreciable amount extends to great distances on either side of the line. Close to the line, but outside the Doppler core, we have

$$a(\nu) \sim \frac{\pi e^2}{mc} \frac{\gamma}{4\pi^2} \frac{1}{(\nu - \nu_0)^2}. \tag{1}$$

Wing scattering of this sort contributes appreciably to the opacity in stars of practically all spectral types. It is particularly important for giant stars of spectral types G5 and later, where intense lines are closely spaced. The proof of the existence of the effect lies in the observational data. As is well known to all observers who have tried to measure absorption lines in late-type stars, the height of the continuous background is not uniform. The rising of the background intensity in regions where lines are spaced unusually far apart shows that wing scattering is effective.

In spectral regions sufficiently far from the line center that the approximation

$$\nu + \nu_0 \sim 2\nu_0, \tag{2}$$

used in obtaining (1), is no longer valid, we must employ the formula:

$$a(\nu) \sim \frac{\pi e^2}{mc} \frac{\gamma}{\pi^2} \frac{\nu^2}{(\nu_0^2 - \nu^2)^2} = \frac{8\pi e^4}{3m^2c^4} \frac{\nu^4}{(\nu_0^2 - \nu^2)^2}. \tag{3}$$

If the frequency ν_0 is small compared with ν, *i.e.*, if the absorption line lies in the infra-red or if the incident radiation is in the extreme ultra-

violet or X-ray region, we may take

$$\nu >> \nu_0, \tag{4}$$

and

$$\alpha(\nu) \sim \frac{8\pi\epsilon^4}{3m^2c^4}. \tag{5}$$

This is the formula we also obtain for scattering of radiation by free electrons. (When an electron is free we may take its fundamental period equal to zero.) Equation (5) is Thompson's formula for X-ray scattering.

If, similarly, the fundamental line lies in the far ultra-violet, we have

$$\nu_0 >> \nu. \tag{6}$$

Then

$$\alpha(\nu) \sim \frac{8\pi\epsilon^4}{3m^2c^4} \frac{\nu^4}{\nu_0^4} = \frac{8\pi\epsilon^4}{3m^2\nu_0^4} \frac{1}{\lambda^4}, \tag{7}$$

and we come to the other limiting case of Rayleigh scattering, with the well-known λ^{-4} law.

Opacity of the sort expressed by equations (5) and (7) will be operative, if at all, only in very hot or very cool super-giant stars, respectively. The fact that the entire terrestrial atmosphere, scattering Rayleigh fashion, produces only a barely appreciable opacity indicates that a great mass of material is required to screen the lower layers of a star sufficiently to form a photosphere.

We should mention, in passing, that the quantum-mechanical analogue of (3) has not yet been given. The possibility of the existence of appreciable deviations from the classical expression should be recognized. Theory indicates that the quantum-mechanical constant Γ, for radiation damping, should be proportional to ν^3 whereas the classical damping constant, equation (1.2), is proportional to ν^2.

The exact formula for scattering by free electrons, as derived by Klein and Nishina, agrees with (5), for light frequencies of astrophysical importance. The effectiveness of electrons in scattering radiation is markedly increased, at from intermediate to high electron pressures, by the presence of positive ions with which they can interact. A free electron may be captured by a proton, for example, on any one of a number of levels. The energy of the free particle is unquantized. Hence the spectral distribution of the emitted radiation is continuous from infinity in the far ultra-violet, redward to a cut-off, corresponding to the capture of a stationary electron in the given quantum level. Thus we have successive continua stretching toward the violet from the limits of the Lyman, Balmer, Paschen, etc., series. The absorption processes are the reverse of the emission, *i.e.*, they consist of photoionization. One should mention that the actual cut-off is never sharp-edged. Broadened quantized or semi-quantized levels, corresponding to high energy states of

the atom, overlap and blend into the true continuum beyond the ionization limit.

The exact formula for the absorption coefficient arising from atomic transitions from a discrete level, n', to the continuum are available for only hydrogenic atoms, of atomic number Z. If R is the Rydberg constant, we have

$$\alpha(\nu) = \frac{\pi e^2}{mc} \frac{2^4}{3\sqrt{3}\pi} \frac{R^2 Z^4}{\nu^3} \frac{1}{n'^5}, \tag{8}$$

for the atomic absorption coefficient per atom in quantum level n'. Transitions from continuous to discrete levels (*i.e.*, free-bound transitions) are closely related to the bound-bound transitions. There exist, also, free-free transitions within the continuum, but the opacity thus produced will generally be negligible compared with that arising from the free-bound transitions. The latter have generally been assumed to be the major source of opacity in stellar atmospheres. In the absence of more precise knowledge concerning the absorption coefficients of ions other than hydrogen, we proceed to apply (8) to the general-opacity problem.

Whether (8) is a satisfactory approximation to the ultimate opacity formula need not now concern us. The present expression exhibits at least one important property of the correct expression—a property that has been somewhat ignored, viz., continuity of the line and continuous spectrum on either side of the series limit. The quantum formula for the integrated absorption coefficient of a hydrogen line is

$$\int \alpha(\nu) d\nu = \frac{\pi e^2}{mc} f = \frac{\pi e^2}{mc} \frac{2^4}{3\sqrt{3}\pi} \frac{R^2 Z^4}{\nu^3} \frac{1}{n'^5} \frac{2RZ^2}{n^3}, \tag{9}$$

where n is the quantum number of the upper level. The line frequencies are defined by

$$\nu = RZ^2 (1/n'^2 - 1/n^2). \tag{10}$$

The number of lines, dn, per frequency interval $d\nu$ is, from (10),

$$dn/d\nu = n^3/RZ^2. \tag{11}$$

Equation (9) represents the absorption of a single line. If we multiply (9) by (11), we evaluate, in effect, the average absorption over the frequency. The result agrees with (8), which proves the continuity of absorption coefficient across the series limit. No matter how complicated the atom may be, we shall still expect to find this continuity preserved.

(3) *Atmospheric Models.* Our own sun is evidence that stellar atmospheres are indeed complicated mechanisms. It would manifestly be inadvisable, if not impossible, to consider at once all of the factors that influence absorption-line formation. The earliest theoretical studies were carried out on a very simple model of the solar atmosphere. The photosphere was assumed to be a distinct radiating surface, with a superposed atmosphere transparent except in the absorption lines.

It is clear, however, that this approximation is far from satisfactory. There is no actual boundary but there is a gradual transition layer, where continuous opacity, actually operative through the entire atmosphere, becomes sufficiently high to produce the illusion of a definite radiating surface. But the transition region is also effective in producing the absorption line. Hence the two effects should be considered simultaneously.

The effects of radiation pressure, convection currents, inequalities of surface temperature, etc., must eventually be considered, but we shall neglect them for the present. It is probable that at least some of these effects have a first-order influence on the true profiles of spectral lines. The appearance of spectroheliograms and the structure of the H and K lines indicate the complexity of the problem. Chromospheric and prominence effects give added complications, which may be predominant in certain types of giant stars.

(4) *Transfer of Radiation.* The problem of calculating profiles of spectral lines has been attacked by numerous investigators. Even the simpler types of problems prove to be so intractable, mathematically, that approximation must be made in the equations before a solution can be obtained. The physical as well as the mathematical portion of the picture also requires simplification. Great care is necessary if the final results are to be representative of actual stars and not a mere reflection of mathematical and physical approximations.

At first sight, in attempting to set up the equations, we meet what appear to be two conflicting and mutually exclusive points of view. Eddington[1] expresses them so clearly that I shall not attempt to rephrase his statements.

"(a) Consider radiation proceeding outwards. It excites atoms and is accordingly absorbed; but the excited atoms subsequently relapse and emit radiation of the same frequency. The emission, however, occurs in all directions equally so that only half of it goes to reinforce the outward beam. Hence absorption followed by emission is equivalent to simple absorption with coefficient $\frac{1}{2}k$, and the intensity in the range ν to $\nu + d\nu$ falls off exponentially giving a very dark line.

"(b) In light of frequency ν to $\nu + d\nu$ we can see only a very small depth into the star since it is highly opaque to this radiation. But the region we do see has a temperature not less than T_0 the boundary temperature, so that the intensity of the radiation in the line should not be less than that corresponding to T_0. Since the surrounding spectrum has an intensity corresponding to $T_e = 1.23\ T_0$ the contrast is very limited."

Eddington concludes that "The first argument is nearer the truth than the second; but we have the uncomfortable feeling that more attention should be paid to the subsequent adventures of the radiation emitted

[1] Internal Constitution of the Stars, p. 337.

backwards. I think it is a not uncommon idea that the Fraunhofer spectrum is caused by a cloud of cooler matter which cuts out the photospheric radiation at frequencies for which it is opaque and substitutes the less intense radiation proper to its own temperature; this is argument (b). It seems best to examine the whole question by an analytical investigation, tracing the formation of absorption lines—under idealized conditions, it is true, but not too unlike the real conditions."

Eddington clearly states his primary assumption, which has generally been adopted axiomatically by most of the further investigators. He says, "We assume the radiation to have the equilibrium constitution with the necessary exception of the absorption line which is being studied."

One objection that has been urged against argument (b) is that, at the limb of a star, the absorption lines should disappear. Looking tangentially through the atmospheric layers, either inside or outside an absorption line, we glimpse levels that have the same boundary temperature and the contrast disappears. I am not convinced that the objection is entirely valid.

There are also several objections to argument (a), some of which have been recognized. As an extreme example, let us consider the line absorption for a simple model, where the photosphere is supposed to be a distinct radiating surface, with an absorbing atmosphere superposed. The differential equation expressing the change of intensity, $I(\nu)$, along the path, the so-called transfer equation, becomes

$$\cos\theta\, dI(\nu)/dx = -N\alpha(\nu)I(\nu), \tag{1}$$

where θ is the angle shown in Figure 6. N is the number of atoms per

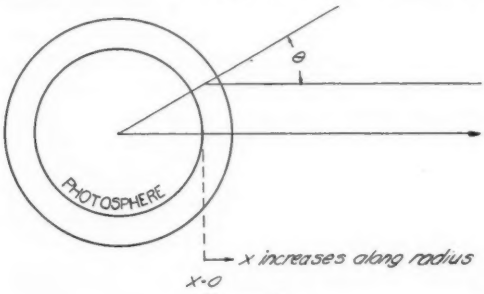


FIGURE 6

cm³ active in absorbing the line in question. $I(\nu)$ is to be regarded as a function of x and θ. The solution of (1) is:

$$I(\nu) = I_0(\nu)\ e^{-[\tau_0(\nu) - \tau(\nu)]\sec\theta} \tag{2}$$

where $\tau(\nu)$, the optical depth, is measured inward from the outer boundary, by

$$[\tau_0(\nu) - \tau(\nu)] = \int_0^x N a(\nu) dx. \tag{3}$$

$\tau_0(\nu)$ represents the optical depth of the photosphere. $I_0(\nu)$ is the intensity of the photospheric radiation. Equation (2), with $\tau(\nu)$ set equal to zero, represents the intensity of the convergent beam as a function of θ. The total flux of radiation, over the surface of a star of radius R, would be

$$2\pi R^2 \pi I_0(\nu) \int_0^{\pi/2} e^{-\tau_0(\nu) \sec\theta} \cos\theta \sin\theta \, d\theta \sim \pi^2 R^2 I_0(\nu) e^{-\tau_0(\nu)} . \tag{4}$$

If $r(\nu)$ is the ratio of the flux at optical depth $\tau_0(\nu)$ inside the line to the flux outside the line, we have

$$r(\nu) \sim e^{-\tau_0(\nu)} . \tag{5}$$

Equation (5) may be a fair approximation to the profile in the extreme line wings. Within the line it will predict too small a value for $r(\nu)$. The predicted line will be too black, chiefly because, in setting up equation (1), we made no allowance for possible re-emission of the absorbed radiation.

An analogous equation given first by Schuster and later by Schwarzschild, which allows in part for the re-emission, is:

$$r(\nu) = \frac{1}{1 + \tau(\nu)} \tag{6}$$

This formula still predicts too "black" a line center. The predicted central intensity is higher, even so, than for Eddington's argument (a), (our equation 5), because the radiation scattered backwards is at least partially taken into account.

In the solar atmosphere, for the average strong line, optical depths of 10^3 or 10^4 at the center are not uncommon. The effective temperature T_0 of radiation escaping from the line centers is extremely low. The order of magnitude is given by

$$e^{-h\nu/kT_0} = r(\nu) e^{-h\nu/kT} \tag{7}$$

where T is the photospheric temperature, with $r(\nu) = 10^{-4}$, *e.g.*, $\nu = 6 \times 10^{14}$ (corresponding to 5000° A) and $T = 6000°$. We find that T_0 is about 3000°.

The observed central intensities are generally very much higher than the simple theory predicts. The same discrepancy appears in all theories involving the assumption of monochromatic radiative equilibrium. If monochromatic equilibrium prevailed, the rapidly diminishing intensity of the radiation beam, in the outer layers of a stellar atmosphere, would be associated with fewer and fewer atomic transitions to excited levels. The number of atoms in these higher quantum levels decrease with the intensity of the ν-radiation. The intensities of absorption lines from the higher levels should be very small. Observation both of absorption lines

and of chromospheric emission show no effect of this sort.

Recognizing the difficulties with monochromatic theories, various authorities have attempted to extend the transfer equations to more general physical conditions. Both Eddington and Milne have attempted to allow for collisional excitation, but the latter seems to have inadvertently removed the effect from his equations in the course of solving them. Woolley introduces considerations of a most important atomic effect, "interlocking," which allows for transitions between several atomic levels, some of which may be continuous.

The equation of radiative transfer as usually employed is expressed in terms of the density and the mass absorption coefficients. When more than one atomic process is considered the assembly of atoms is ordinarily divided into two or more parts, each of which is carrying on some special activity, one producing line absorption, another taking part in collisional excitation with subsequent emission, etc. There is nothing formally wrong with either of these procedures. Collisional excitation or de-excitation, and atomic transitions not involving direct absorption or emission of the frequency ν, do have a direct influence on the intensity of a spectral line, because they determine in part the number of atoms in the lower and higher of the atomic levels acting to produce the given line.

But these extraneous processes should not appear directly in either the equations of *radiative transfer* or of *radiative equilibrium;* the absorption and emission depend on the populations of the states directly involved and on the intensity of the incident radiation. Collisions, captures, etc., should rather appear in the equations of *statistical equilibrium,* which demand that the physical state of the assembly be constant with time. As certain quantities are eliminated from the transfer equation by means of the equation of statistical equilibrium, the collisional terms will then appear. Putting them in originally for any atom with more than two levels involves four-dimensional mental gymnastics beyond my own ability, at least. Finally, since the physics of the picture are kept more easily in mind, when numbers of atoms per unit volume and atomic absorption coefficients are employed rather than density and mass absorption coefficients, I prefer to use the former.

(5) *The Stellar Continuum.* To illustrate the problem we shall first examine the transfer of radiation in an atmosphere consisting mainly of hydrogen. We shall further suppose the temperature of the star to be sufficiently high that an appreciable number of atoms are found in the higher atomic levels. Let N be the total number of hydrogen atoms per cm^3, of which N_0 are neutral and N_i are ionized. Let $N\epsilon$ be the number of electrons per unit volume. In thermodynamic equilibrium the number of atoms in quantum level, n, of the neutral atom will be:

$$N_{nT} = N_0[\tilde{\omega}_n/b_T(T)]\, e^{-(E_1-E_n)/kT} \quad . \qquad (1)$$

The number of ionized atoms is determined by the dissociation formula:

$$\frac{N_{iT}N_{\epsilon T}}{N_{0T}} = \frac{(2\pi mkT)^{3/2}}{h^3}\,\frac{2}{b_T(T)}\,e^{-E_1/kT}\,, \tag{2}$$

where the subscript "$_T$" indicates thermodynamic values.

$$E_n = hR/n^2, \tag{3}$$

the ionization potential from level n. The statistical weight, including electric spin, is

$$\tilde{\omega}_n = 2n^2 \tag{4}$$

and the partition function

$$b_T(T) = \sum_1^{n_{max}} \tilde{\omega}_n\, e^{-(E_1 - E_n)/kT}\,, \tag{5}$$

n_{max}, determined by the so-called "excluded volume" correction, is given accurately enough by:

$$n_{max} \sim (N a_0^3)^{-1/6}. \tag{6}$$

a_0 is the radius of the one-quantum orbit of hydrogen.

A stellar atmosphere, however, cannot be in true thermodynamic equilibrium. The very fact that there is outflow of energy accompanied, of course, by a temperature gradient, precludes the possibility of equations' (1) and (2) holding exactly; the physical state of the assembly can no longer be described in terms of a single temperature parameter T. Each portion of the assembly must be described by a different T or by some arbitrary parameter.

There is one part of the assembly, however, where thermodynamic conditions will obtain very closely, viz.: the ionized portion, where the velocity distribution of the free electrons will be nearly Maxwellian. I believe that no very great error is introduced if we take the distribution of electron velocities to be *exactly* Maxwellian at electron temperature T. This assumption takes the place of the one made by others who introduce the condition of *"local* thermodynamic equilibrium." The present assumption requires that the continuous emission, per unit volume, resulting from total or partial captures of electrons be equal to that from an equal volume in thermodynamic equilibrium, with the atom density so adjusted that

$$N_i = N_{iT} \quad \text{and} \quad N_\epsilon = N_{\epsilon T}. \tag{7}$$

Since the ionized portion of the assembly is held to be in thermodynamic equilibrium, we shall find it convenient to refer the population of discrete levels to the continuum of ionized levels, where the electron temperature in the usual kinetic sense is T_e. We may write, instead of (1), (2), and (5),

$$N_n = b_n N_0 [\tilde{\omega}_n / b(T)]\, e^{-(E_1 - E_n)/kT_e}\,, \tag{8}$$

$$N_i N\epsilon / N_0 = \frac{(2\pi mkT_e)^{3/2}}{h^3} \frac{2}{b(T)} e^{-E_1/kT_e}, \tag{9}$$

and

$$b(T) = \sum_1^{n_{max}} b_n \tilde{\omega}_n e^{-(E_1 - E_n)/kT_e}, \tag{10}$$

b_n is a dimensionless factor, which equals unity when thermodynamic equilibrium obtains.

We shall frequently find it more convenient to employ, instead of equation (8), the following expression for N_n:

$$N_n = b_n N_i N\epsilon \frac{h^3}{(2\pi mkT_e)^{3/2}} \frac{\tilde{\omega}_n}{2} e^{E_n/kT_e} \tag{11}$$

which, when summed over n, is seen to be equivalent to (9). I have found this notation particularly useful in discussing the physical conditions in gaseous nebulae.

The equations of transfer for a hydrogen atmosphere prove to be quite involved. We shall therefore not write them down explicitly. Instead we shall consider the important features of the problem. As a result of equating, for each atomic level, the number of atoms entering to the number of atoms leaving by every conceivable process, we finally obtain, as the solution of an infinite series of simultaneous linear equations, the values of b_n. Since the incident radiation plays an important part in determining certain coefficients of these equations, viz., those defining the number of radiational excitations from one atomic level to another, we cannot evaluate the b_n's from the equilibrium relationships until the transfer equations are solved. But the transfer equations, in turn, are clearly dependent on the b_n's. The continuous absorption beyond the Balmer limit, for example, will depend upon the value of b_2, which fixes the number of 2-quantum atoms. The general solution evidently consists of a combination of the equilibrium and transfer equations. As a final complication, there must be an equation that guarantees conservation of energy, in all absorption and emission processes. It is this last equation, used in combination with all the others, that finally enables us to evaluate the electron temperature, T_e, and the percentage ionization.

Amid the chaotic jumble of equations, we see one hope of obtaining order, viz., application of the principle expressed in equations (2.9) *et seq.* The continuity of the absorption coefficient over the series limit must still occur. The assumption of the existence of an electron temperature, with attendant Maxwellian distribution, is equivalent to adopting $b_n = 1$ for the energy levels of the continuum. The discrete levels, then, must fulfill the condition

$$b_n \to 1 \quad \text{as} \quad n \to \infty, \tag{12}$$

for continuity to be fulfilled.

A detailed study of the statistical problem for an idealized type of planetary nebula has shown the validity of (12) under even these extremes of physical conditions. Further investigation of equilibria for conditions more nearly approaching those existing in stellar atmospheres, higher densities, less diluted radiation, etc., indicates a very close approach of the b_n's to unity. This approach to unity is seen to rest on the continuity of the discrete and continuous atomic levels. Approximations that do not recognize the continuity are likely to lead to false results.

The close approach to conditions of thermodynamic equilibrium, with the temperature of the electron gas approximating to the temperature of the incident radiation, means that each atomic process is very nearly balanced by its reverse. The flux at a given frequency is thus determined by the minute difference between two large, almost equal quantities. As every computer knows, extremely high accuracy is required in such circumstances, to insure the reality of the calculated difference.

(To be continued)

Joel H. Metcalf, Clergyman-Astronomer

By RACHEL METCALF STONEHAM

My father bundled me up when I was two years old and took me out of doors at midnight to see an eclipse of the moon. From then on, stargazing became a common occurrence of my girlhood, for my father's devotion to his job, the ministry, hardly surpassed his consuming passion for his hobby, astronomy. Years before the Scope's evolution trial or any of the events that led up to it, my father, Joel H. Metcalf, had reconciled his two chief interests, believing with the poet, Edward Young, that "the undevout astronomer is mad."

Religion came in large doses to us youngsters on Sundays and often during the week, but astronomy came with almost every meal and we took it with the same matter-of-factness as we took our bread and butter. It wasn't that father exactly wanted an audience, but rather that he thought better out loud. So, at meal times, we listened, not always impatiently to the latest discoveries or the most recent theories of space, and we gradually and painlessly learned to understand advanced astronomy without ever having learned the elementary part. We could speak glibly of sidereal time, right ascension and declination, light years, the spectroscope and later, even the Einstein theory. Curved space did not bother father and as he explained it to us, it all seemed quite logical and easy to understand. As sugar was sprinkled on our oatmeal, so astronomy was sprinkled over our family life.

Occasionally we could tease father into astronomical reminiscences. Then we were delighted and, of course, we soon knew the stories by heart, along with Cinderella and the Three Bears. Oddly enough, it was

through the Sunday School that father first caught a glimpse of the possibilities of the heavens. When he was fourteen years old, he took from the Sunday School library a book called "Other Worlds Than Ours" by Richard Proctor. This book became an open door through which he had visions of the Universe beyond. At about that time, Mars and Jupiter came into conjunction, and, spurred by the book, young Joel sat under the stars in his backyard, watching the phenomenon. After this first sip, nothing could quench his thirst for knowledge about the heavens.

A schoolmate of his, always confused in my childish mind with Tom Sawyer, found a three-inch telescope objective in an abandoned house, and the boys swapped marbles and jack knife for telescope. Grandmother never had any money for luxuries, and young Joel had to plead long and to carry many an extra armful of wood before she could be persuaded to give him the six dollars necessary to have the lens mounted. Soap boxes and old wood from the barn made an excellent stand—his first observatory. Father never admitted it, but grandmother said that she always suspected that her son climbed out the window many a clear night after he had been sent to bed.

His first real telescope came into the family just before I did. Father saw an advertisement of a fine seven-inch telescope (that means that the lens was seven inches in diameter) to be sold to close an estate in New York. He wrote and made an offer of five hundred dollars. As soon as his bid had gone, he was in an agony of doubt whether he had offered enough. He had. Then, of course, he wondered whether he need have offered that much.

He lived in Burlington, Vermont, at that time, and winter had frozen Lake Champlain for many inches. So, he decided to bring the telescope and its dome across on the ice with sleds and horses. All went well until, quite suddenly the ice cracked. Horses and men jumped, but the instrument fell with a heavy thud, lying across the opening, neither in nor out. They dared not move it lest the parson's recent extravagance sink to the bottom. It was many long years before "wrecking-cars," so several men worked with a derrick almost a week to get this ungainly, heavy and expensive gadget safely onto dry land.

All this belongs to the years before my time. But during his next pastorate, I became well initiated into his astronomical *mores*. Out in our parsonage yard stood a square frame observatory not unlike a modern garage, except that the peaked roof divided into two parts which pulled out on runners like large shelf brackets. With its roof slid back, the telescope could stick out like a snail from its shell, and point in any direction. The ropes from the roof dangled sufficiently low so that, by jumping, we children could just catch hold, and, hanging on like monkeys, have a leisurely ride to the ground. If the observatory was unlocked, as usual, my friends and I would tiptoe inside and repeat the process to close the roof again. The fact that we were playing around a costly and carefully adjusted instrument did not impress us.

When we tired of monkey rides, we would travel the strange flight of steps inside, which led to nowhere, and which could be easily wheeled around. The treads of these stairs were hinged, so that the observer could use any step as a seat from which he could squint into the insignificant eyepiece with the telescope pointing in any direction. In more than one Unitarian parsonage yard, the enormous cement block, which served as base for the telescope, still stands like a gravestone, for other little parsonage children to clamber over.

JOEL H. METCALF

The observatory had more uses than this for us youngsters. On tiresome Sunday afternoons, when books and quiet games had been tried and found wanting, and when brother and I would start the inevitable "rough house," my mother would say, "Go chase each other ten times around the observatory." We would, and if by chance, we came in still full of pep, we took a second dose, and then willingly sat down peaceably exhausted.

My prestige among my playmates grew apace upon the approaching visit of Halley's comet, for I gave everyone tacitly to understand that it

was appearing because of a cordial invitation from my father. Of course, I was the only child of my age who knew what a comet was, and I explained often and verbosely, only too glad to find my father's hobby of some use. Once in a while, we had star-gazing parties, when parishioners and other friends would come to exclaim over the rings of Saturn and to ask if Mars were inhabited. But nothing equalled the pleasure of "demonstrating" Halley's comet to an awe inspired group of young and old.

Summers, during my father's long vacations, if he were not travelling in Europe, he was sure to be making telescope lenses at our camp. This highly specialized art was more of a gift than a science for there was no authoritative book at that time on grinding, polishing, and computing the curves of lenses. The sixteen-inch lens for the photographic telescope at Harvard University, was made under the pine trees within view of Lake Champlain, and I felt personally responsible for its ultimate success.

Everything was grist to my father's mill, and expensive apparatus was unthinkable. So with a barrel for a table and a packing box for a chair, he would sit for hours swishing the sixteen-inch lozenge of glass, one inch or so thick, around and around on a curved surface of carefully prepared beeswax and rouge,—around and around and around, with a patience he did not often evince in other projects. Hours and days and weeks, with the care of a surgeon during a critical operation, he smoothed the curves to a fraction of a millimeter. Hour after hour, mother and I took turns reading to him on every conceivable subject, for while his hands were busy, his brain could be gathering material for another year of the inevitable sermons.

When the curves had to be checked, we hung rain-coats over the windows in a little side room of the cottage, and even stuffed up the knotholes. Then I proudly held a lighted candle just so, behind a piece of thick paper with a pin prick in it, in a miniature imitation of Venus. Father looked through the lens at this prick of light from a certain distance and vouchsafed the one word, "hmmmm." What he saw, I never knew, but whatever it was, it told him whether to grind or polish more on this side or that, and the resulting telescope from these makeshift operations has served Harvard long and well. Many years after, the lens, upon which he was working at the time of his death, was later finished with difficulty and used in the recent discovery of our newest planet, "Pluto."

Winter astronomy was prosaic and, one might say, impersonal. How my brother hated those long, black lonesome nights, when, bundled to the teeth but adequately paid, he had to keep the telescope camera trained upon a certain heavenly object. The photographic plates when developed, looked like a diagram of a bad case of chicken pox. But each pock mark had a meaning for father. By careful examination, and by superimposing one plate upon another of the same region taken a differ-

ent night, he could spot hitherto undiscovered heavenly objects. In all, he found about sixty asteroids, or minor planets, or an average of one for every year of his life—a truly enviable record.

But summer astronomy was thrilling and personal. How my father loved those long, black, friendly nights, when he could sweep the heavens, oh, so slowly and carefully, hour after hour, with his comet-seeker. An unknowing reporter of that time wrote that "Mr. Metcalf packed his trusty telescope in his clerical portmanteau and went forth to his summer home in search of comets." His trusty telescope weighed over two hundred and fifty pounds and the portmanteau in which it was transported was a box seven feet long and three feet wide, resembling the coffin of some giant. Summers this instrument in its coffin lay on top of a little hill in back of our cottage, in a neighboring cow pasture.

A lovely evening with a full moon was not a lovely evening to father. He wanted only a moonless, star-spangled, black velvet night. Comets are shy creatures and disguise themselves often as nebulae. Even through father's powerful comet-seeker, they looked merely like fuzzy dots in a field of bright pin pricks. Not every summer could yield a comet, but, like fishing, the fun seemed to be in the fishing itself as well as in the catch.

Days he spent grinding and polishing his lenses, or fishing for bass in Lake Champlain, but on dark cloudless nights, he fished for comets on the hill. With a little oil lantern he would wend his eager way over the stile and in and out the hummocks to set up his comet-seeker. This looked like nothing half so much as six feet of aluminum stove pipe, but it was really an expensive and delicately balanced instrument, easily set on a sort of tripod. His seat was a low semi-circular bench just the right height so that he could get the maximum horizon with the minimum of adjustment. Footsteps of friendly cows or the galloping of frisky horses allowed to roam at night kept father company in the dark, and once, as he lighted his lantern, he gazed with horror into the placid eyes of a skunk, which only looked and walked away.

Mother and I were used to father's late hours and would hardly more than stir when he quietly closed the screen door and tiptoed on every squeaking board on his way to bed. Once in a while we would be instantly roused by father's thunderous whisper to mother, "Elizabeth! I think I've got one." Day times "one" would indicate a bass or pickerel, but nights it meant a comet. And, at once, we bounded out of bed, lit lamps, brought out maps—everyone talking at the same time.

If the maps indicated no black dot at the precise spot at which father had seen something fuzzy, then we knew that what he "had" was either a comet or a nebula, and only an hour or more of waiting would tell us which. Nebulae were like rock bass to be tossed back into the void as worthless. But comets were a priceless catch. Comets move, but nebulae are stationary. So when, after an hour of impatient waiting, father

trudged back to the hill, we three could hardly contain ourselves for excitement, hoping that the dot had moved.

Once in a while, of course, there were false alarms, but father's trained eye seldom betrayed him. Automobiles and telephones have taken the romance from astronomy, but one dark night in August when I was eleven years old, father really "got" one. The next step was to send word to the Observatory at Harvard. Our camp was a half mile from the nearest telephone, which had sixteen people on the line. At 2:30 A.M. a jangle on the phone would have brought sixteen sleepy families to listen in. That method was unthinkable, not only out of kindness to them, but also because father could not have heard well with sixteen receivers off—he had tried it before. Neither could he have stood the suspense of a three mile walk (for we had no car) to the village. So we instantly knew that our only means of communication with civilization was by way of a two-mile trip by water and a half-mile walk to the village store and post-office.

We had a row boat with an engine of sorts in it and luckily I knew how to run it. Father was in no condition to be mechanical. So while poor mother stayed home (the boat held only two) and saw us wrecked on every reef, we started bravely out. The boat was rickety, the batteries weak, the gasoline low, and the oil lantern our only light, with the stars for our guide. Not a single light twinkled on shore. We gave the first reef a wide berth and took the deepest water down the bay. Finally, slowing down to the merest put-put, we closed in on shore and found the dock by bumping into it gently, head on.

Father was striding off with the lantern while I was still tying up the boat, and I dashed, panting, after him as best I could. We banged and called until a terrified postmaster let us in, much relieved to know that the whole village was not afire and that we only wanted to use his telephone. I heard him mutter something under his breath about these danged city-folks. Then, while I sat on a counter surrounded by candy, dress goods, fish hooks, seeds, kitchen and farm implements, as well as the politely interested but scantily dressed postmaster and his wife, father put in a long distance call to Cambridge. His calm controlled voice belied his smouldering excitement, and one would have thought he discovered a comet at least once every night. His message delivered, giving the exact position of the fuzzy spot, we could take our weary way homeward with a jug of gasoline for the almost empty tank. Our own dock could not stand being bumped so we shut off the engine and rowed quietly up to poor mother who, no doubt, had been wondering whether comets were really worth the trouble.

Uneasy rests the head which has just discovered a comet, for nights are dark and astronomers avid in more than one place, and many eyes were straining to find little fuzzy spots that same night. So, not until he received corroboration next day, was father quite sure that the comet was, indisputably, his. One comet, years later, in the unromantic auto-

mobile age, was discovered simultaneously by father and an European astronomer so they had to share the honors. Much more important but not half as much fun was when father startled the world by the discovery of two comets in three nights. As a matter of fact, he discovered three comets in three consecutive nights, but, unfortunately for him, one of them was an independent discovery of one already known, but which had unexpectedly changed its timetable. This record, I believe, has not been equalled by professional astronomers.

Now there are six Metcalf comets (one hyphenated with the European) which run their computed orbits around through the years, a perpetual memorial to their discoverer. It has been many years since I have been telescope making or comet seeking with father, but every black velvet night I still think, "What a wonderful night for comets."

61 Chapman Street, Canton, Massachusetts.

Planetary Phenomena in 1939

By R. S. ZUG

Note. The data utilized in this article are taken chiefly from the *American Ephemeris and Nautical Almanac.* The information regarding occultations of stars by planets was taken from the article "Occultations by Planets," by Arthur Burnet, published in *The Handbook of the British Astronomical Association.* The position of Pluto was secured from the *Berliner Astronomisches Jahrbuch.*

Universal or Greenwich Civil Time is employed unless otherwise stated. This is Standard Time in England, and is reckoned from Greenwich midnight through 24 consecutive hours.

Eclipses

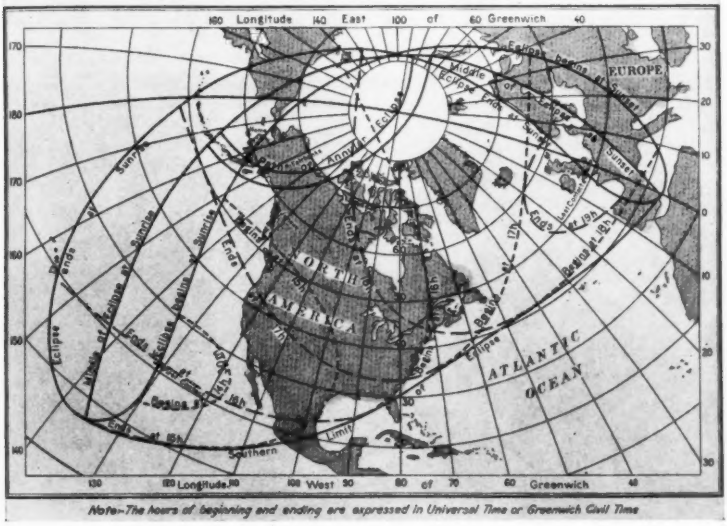
There will be two lunar and two solar eclipses in 1939.

I. *An annular eclipse of the sun will occur April 19, 1939.* The duration of the annular phase of the eclipse will be about $1^m\ 50^s$ for stations along the central path The path of the annular eclipse begins in the Aleutian Islands near Unalaska Island, and proceeds eastward, taking in the Alaska Peninsula and the southern coast of Alaska. Seward, Alaska, seems centrally located in the path of the annular eclipse, which is about 200 miles wide. The path then runs in a northeasterly direction, crossing Dawson and the Klondike gold fields, then out over the Arctic Ocean, touching such isolated land areas as Parry Island and Crocker Land, to pass just to the south of the north pole in longitude 30° W. The path ends off the Arctic coast of Russia, near the northern tip of Nova Zembla. The partial phase is visible over a large portion of the North American continent, Europe, and eastern Russia. Last contact occurs at sunset in southern England.

In the eastern part of the United States the partial eclipse lasts from about 11:00 A.M. to 1:00 P.M., Eastern Standard Time. In the central states, the corresponding interval is from about 9:30 A.M. to 11:30 A.M., Central Standard Time. In

western United States the eclipse lasts from about 6:45 A.M. to 9:00 A.M., Pacific Standard Time. For any particular locality the time of first and last contacts can be estimated with the aid of Figure 1, with an uncertainty of but a few minutes. Figure 1 also allows an estimation of the magnitude of the eclipse at any point. The magnitude varies considerably over the United States. For example, in California about 0.5 of the sun's disk (in terms of diameter) will be obscured at time of maximum eclipse. Corresponding values for other regions are as follows: Idaho, 0.6; Texas, 0.2; New York, 0.2; South Carolina, 0.07; Wisconsin, 0.4. These values vary somewhat within a state, depending upon the latitude and longitude. Local circumstances of the eclipse are given for 74 cities in the United States on pp. 589-590 of the *American Ephemeris and Nautical Almanac* for 1939.

ANNULAR ECLIPSE OF 19 APRIL 1939



Note—The hours of beginning and ending are expressed in Universal Time or Greenwich Civil Time

Circumstances of the Eclipse:

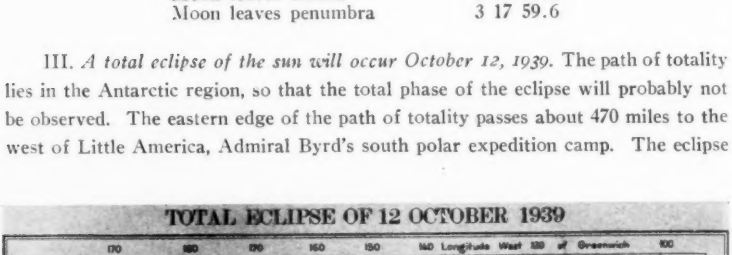
	G.C.T.	Longitude	Latitude
	d h m	° ′	° ′
Eclipse begins	April 19 14 26.0	+131 5	+21 39
Central eclipse begins	19 16 7.3	+167 22	+53 41
Central eclipse at local app. noon	19 17 14.0	+ 78 42	+88 23
Central eclipse ends	19 17 23.2	— 76 42	+78 6
Eclipse ends	19 19 4.6	+ 2 19	+51 8

II. *A total eclipse of the moon will occur May 3, 1939.* The beginning of the eclipse will be visible generally in Alaska, the Pacific Ocean, Australia, Polynesia, the Antarctic Ocean, the Indian Ocean, and eastern and central Asia. The ending will be visible generally in the western part of the Pacific Ocean, Polynesia, Australia, Asia, the Antarctic Ocean, the Indian Ocean, Madagascar, Africa, except the northwestern part, and the eastern part of Europe. The eclipse is invisible from North and South America, except Alaska.

Circumstances of the Eclipse:

	Greenwich Civil Time d h m
Moon enters penumbra	May 3 12 23.4
Moon enters umbra	3 13 27.6
Total eclipse begins	3 14 39.5
Middle of eclipse	3 15 11.2
Total eclipse ends	3 15 42.9
Moon leaves umbra	3 16 55.0
Moon leaves penumbra	3 17 59.6

III. *A total eclipse of the sun will occur October 12, 1939.* The path of totality lies in the Antarctic region, so that the total phase of the eclipse will probably not be observed. The eastern edge of the path of totality passes about 470 miles to the west of Little America, Admiral Byrd's south polar expedition camp. The eclipse


TOTAL ECLIPSE OF 12 OCTOBER 1939
PACIFIC OCEAN
AUSTRALIA
Total Eclipse
Sunrise
Sunset
Longitude East of 100 Greenwich
Note:- The hours of beginning and ending are expressed in Universal Time or Greenwich Civil Time

can be seen as partial in the eastern part of Australia, where it will be partially eclipsed at sunrise on the morning of October 13, Australia Standard Time. In New Zealand, first and last contacts will occur at approximately $6^h\,15^m$ in the morning and $12^h\,20^m$ noon, October 13, New Zealand Standard Time. This information is taken from Figure 2. The partial eclipse will be visible as far north as the Fiji Islands in the longitude of New Zealand. The eclipse will be visible as partial from the southern part of Argentina in the late afternoon of October 12. Last contact occurs at sunset of October 12, off Cape Horn.

Circumstances of the Eclipse:

	G.C.T. d h m	Longitude ° ′	Latitude ° ′
Eclipse begins	Oct. 12 18 34.7	—164 59	—22 22
Central eclipse begins	12 20 17.2	—129 34	—60 00
Central eclipse ends	12 21 2.3	— 72 33	—81 28
Eclipse ends	12 22 45.0	+ 63 48	—55 34

IV. *A partial eclipse of the moon will occur October 28, 1939.* This eclipse is almost total, the magnitude of the eclipse being 0.992 at maximum. The eclipse is visible generally in Europe except the extreme eastern part, the western part of Africa, the Atlantic Ocean, North and South America, the eastern part of the Pacific Ocean, and the northeastern extremity of Asia. The ending is visible generally in the North Atlantic Ocean, the Arctic Ocean, North and South America, the Pacific Ocean, Polynesia, the eastern part of Australia, and northeastern Asia. This eclipse should prove an interesting spectacle for observers in North and South America, since the entire eclipse will be visible from these continents. For them, the beginning will occur on the evening of October 27, and the ending on the morning of October 28.

Circumstances of the Eclipse:

	Greenwich Civil Time d h m
Moon enters penumbra	Oct. 28 3 41.8
Moon enters umbra	28 4 54.5
Middle of eclipse	28 6 36.2
Moon leaves umbra	28 8 18.2
Moon leaves penumbra	28 9 30.9

Visibility of the Planets

The visibility of the planets for any date may be found from examination of Figure 3, prepared this year by the author, in view of the inability of Mr. William Malcolm Browne, formerly of the United States Naval Observatory, to continue this service. Figure 3 shows for any date the difference in right ascension between each planet and the sun. If the graph of a planet lies to the right of the zero line on a given date, the planet is a morning star. If to the left, then the planet is an evening star. A planet should be one or two hours east or west of the sun to be easily observable in the evening or morning sky, as the case may be. Where the graph pertaining to a given planet intersects the 12-hour line, the planet is in opposition, and the corresponding ordinate gives the date of opposition. Where a graph crosses the zero line, conjunction of the sun is indicated. When the graph pertaining to a superior planet crosses the zero line, the planet is, of course, in superior conjunction on the corresponding date. An inferior planet may be in superior or inferior conjunction, depending on whether it had previously been a morning, or evening, star, respectively. Where two graphs intersect, the corresponding planets are in conjunction with one another on that date. The declination of each planet is indicated at intervals along the respective curves, usually at points corresponding to dates upon which the declination attained an integral number of degrees. Where the declination is given to the tenth of a degree, it usually signifies a maximum or minimum was reached on the day in question.

Mercury. The year opens with Mercury a morning star near greatest western elongation. This is not a very favorable elongation for northern observers, because of the planet's southerly declination. Observers in the northern hemisphere will have opportunity for locating and studying Mercury near March 17, when the

VISIBILITY OF THE PLANETS FOR 1939

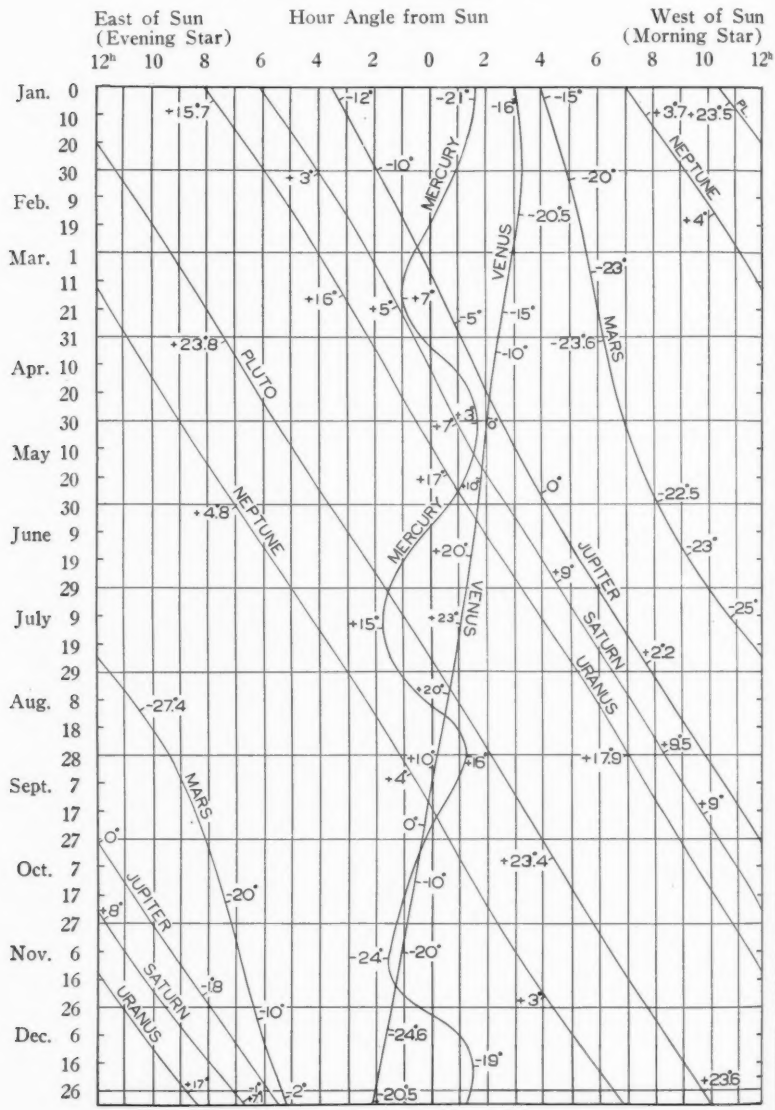


FIGURE 3

planet will be an evening star at greatest elongation east of the sun, or later around July 13 at the next eastern elongation.

The greatest elongations of Mercury during 1939 are listed below, with the stellar magnitude of the planet on each date.

GREATEST ELONGATIONS OF MERCURY FROM THE SUN

Eastern Elongations (Evening Star)				Western Elongations (Morning Star)			
Date		G.E. East	Stellar Magn.	Date		G.E. West	Stellar Magn.
d	h	° ′		d	h	° ′	
Mar. 17	1	18 27	0.0	Jan. 3	10	22 49	—0.1
July 13	19	26 31	+0.7	May 1	9	26 55	+0.7
Nov. 8	3	23 10	0.0	Aug. 28	7	18 16	+0.1
				Dec. 17	0	21 25	—0.2

For southern observers the most favorable opportunity for evening observation will occur at the time of the greatest eastern elongation of November 8.

Mercury passes 45′ to the south of Saturn on May 10, 15^h, when the two planets are in conjunction. An occultation of Mercury will occur December 9, 9^h, but at that time the planet will not have risen for observers in the United States.

Venus. On January 1, Venus is a brilliant morning star of magnitude —4.4. It is to be seen in the southeastern sky before sunrise, for northern observers. It is, of course, bright enough to be seen with the naked eye in the daytime. The elongation from the sun is increasing during January, and on January 30 becomes a maximum, reaching a greatest western elongation of 46° 56′. The stellar magnitude will then be —4.1. Superior conjunction with the sun is reached September 5, when the planet becomes an evening star. By October 1 it should be plainly visible in the evening sky shortly after sunset. Data of interest to observers are given in the following table. The columns are self explanatory.

Date, 1939	Distance from earth miles	Angular Diameter	% of disk seen Illuminated	Stellar Magnitude
	VENUS (MORNING STAR)			
January 1	41,990,000	37″.2	0.32	—4.4
January 31	62,820,000	24.8	0.50	—4.1
March 1	83,280,000	18.7	0.63	—3.8
April 1	104,020,000	15.7	0.74	—3.6
May 1	122,200,000	12.7	0.82	—3.4
June 1	138,190,000	11.3	0.90	—3.3
July 1	149,350,000	10.4	0.95	—3.3
August 1	157,720,000	9.9	0.99	—3.4
September 1	160,420,000	9.7	1.00	—3.5
September 5, 20^h, Superior Conjunction with the Sun.				
	VENUS (EVENING STAR)			
October 1	158,480,000	9.9	0.99	—3.4
November 1	152,470,000	10.2	0.97	—3.4
December 1	143,380,000	10.9	0.93	—3.3
December 31	131,480,000	11.9	0.88	—3.4

On January 17, Venus occults the 7.6 magn. star, B.D. —17°4616. The occultation is visible in North America, and the duration of it is, approximately, from January 17, $13^h\,15^m$ to January 17, $13^h\,40^m$.

Earth. The earth is in perihelion January 3, 22^h, and in aphelion July 5, 20^h. Spring begins as the sun crosses the vernal equinox, March 21, $12^h\,29^m$. Summer begins at the instant the sun reaches the summer solstice, June 22, $7^h\,40^m$. Fall

begins with the passage of the autumnal equinox, September 23, $22^h\ 50^m$, and winter begins December 22, $18^h\ 6^m$, with the passage of the winter solstice.

Mars. Mars will be in opposition with the sun on July 23, 8^h, and will reach a minimum distance from the earth of 36,033,000 miles on July 27, 21^h. When closest to the earth it will be located in the southwest corner of the constellation Capricornus in position, $\alpha = 20^h\ 8^m$, $\delta = -26°\ 46'$. The southerly declination at time of opposition is unfavorable for observers in the northern hemisphere, but an advantage for observers in the southern hemisphere, as for the latter it means a large meridian altitude and optimum seeing conditions. Mars is in perihelion September 17, and on July 27 it is nearing its closest approach to the sun. The resulting minimum distance from the earth is only 4% greater than the minimum possible distance at opposition (minimum possible, 34,600,000 miles). The opposition is therefore of considerable importance to planetary observers. Data pertaining to the opposition are listed below.

MARS

Date, 1939	Distance from earth miles	Angular Diameter	Stellar Magnitude
May 1	76,693,000	11".3	—0.2
June 1	55,310,000	15.7	—1.2
July 1	40,776,000	20.3	—2.1
July 27.9	36,033,000	24.1	—2.6
August 1	36,144,000	24.1	—2.5
September 1	43,173,000	20.1	—1.8
October 1	56,960,000	14.2	—1.0

The apparent path of Mars in 1939 begins in the constellation Libra. The planet's motion is eastward until June 24, when the motion becomes retrograde. The planet then retrogrades through opposition and until August 24, describing a loop shaped path in the southwest part of Capricornus. Thereafter the motion is direct, and by December 31 the planet is but a few degrees from the vernal equinox.

An occultation of Mars occurs January 14, 21^h, visible from eastern Asia, Australia, and New Zealand. On February 12, 12^h, the moon will pass 1° 40′ to the north of Mars, providing an interesting conjunction for observers in North and South America.

Jupiter. Jupiter is an evening star during the first part of 1939. Conjunction with the sun occurs March 6, at which time the planet becomes a morning star. Western quadrature is reached June 30. Opposition occurs September 27, 19^h, at which time the distance from the earth, and the angular polar diameter will be, respectively, 367,100,000 miles, and 46".5. The stellar magnitude of the planet varies from —1.6 in January to —2.5 at opposition, and back to —2.0 by December 31. Eastern quadrature occurs December 18, so that the year ends with Jupiter an evening star near the meridian at nightfall.

Jupiter moves from the constellation Aquarius into Pisces during 1939. On May 10, the planet will be situated on the equinoxial colure, 1° 8′ south of the vernal equinox. In the months following this date the planet will in its apparent motion describe a narrow loop about 10° in length just east of the vernal equinox. The motion is direct until July 30. It is then retrograde until November 25, when direct motion is again resumed. By December 13, the planet has completed the long narrow loop, and is on the equinoxial colure for the second time during the year. The declination this time is —1° 30′.

Jupiter occults two stars during 1939: (1) B.D. +1°93, magn. 9.0, July 11-12;

and (2) B.D. —1°3, magn. 9.0, October 19-20. In the case of (1), the immersion will be visible in Central and Western Asia, Africa, and Eastern Europe; the emersion in Africa and Europe. The period of occultation is, approximately, from July 11, $21^h\,15^m$ to July 12, $1^h\,35^m$. The second occultation (2) will be visible throughout Europe, Africa, Central and Western Asia, and South America. The emersion, and possibly the immersion, should be visible also from the eastern portion of North America. The period of occultation is, approximately, from October 19, $22^h\,5^m$ to October 20, $0^h\,10^m$.

Saturn. Saturn is to be found in the constellation Pisces during 1939. It is an evening star until conjunction April 11, and is then a morning star until opposition, which occurs October 22. After opposition the planet is an evening star for the duration of the year. The view of the rings is steadily improving. On January 1, the angular dimensions of the major and minor axes of the outer ellipse of the outer ring are, respectively, 40″.5 and 5″.8; at opposition October 22, the corresponding values are 45″.2 and 11″.5. The southern side of the rings is now visible from the earth. The stellar magnitude of the planet varies from +0.9 on January 1 to +0.1 at the time of opposition.

An occultation of the 8.5 magn. star, B.D. +6°259, by Saturn is predicted for November 25, visible in North and South America. The immersion of the star behind the planetary disk occurs at $3^h\,18^m$, and the corresponding emersion at $5^h\,20^m$, roughly. These figures vary a few minutes for different stations. Emersion from the ring takes place at $6^h\,38^m$, within a few minutes. The time of first immersion behind the ring system is at present unpredictable with satisfactory accuracy, according to Mr. Burnet.

Uranus. Uranus will be situated in the constellation Aries during 1939. Conjunction with the sun occurs May 9, and opposition November 13. Eastern and western quadratures occur, respectively, February 3 and August 15. The right ascension and declination of Uranus are listed each month in "Planet Notes." Observable occultations of Uranus will occur on the dates listed below. The dates, as given, refer to the instant of conjunction in right ascension of Uranus and the moon. If the occultation is visible in the United States, local circumstances of the eclipse will be published in advance for three standard stations. By interpolation, similar data can be secured for any station in the United States.

OCCULTATIONS OF URANUS

Time of Conjunction				Time of Conjunction			
	d	h	m		d	h	m
January	1	18	9	March	24	16	24
January	29	2	15	June	15	0	24
February	25	9	10	July	12	11	57

Neptune. Neptune will be in opposition with the sun March 13, and in conjunction September 16. The path of Neptune to August 1, 1939, is illustrated in Figure 4, reproduced from "Planet Notes for December, 1938." The star background has been copied from the B.D. (Bonn Durchmusterung) star maps, and the path of Neptune superimposed, allowance being made for precession. The position of Neptune for the first of each month is indicated. The smallest dots represent stars of from 9.5 to 10.0 magnitude. Two stars, 84 (τ) Leonis, magn. 5.2, and 89 Leonis, magn. 5.8, which are present on fairly detailed star charts such as *Norton's*, are shown on the chart. The chart is arranged for use with an inverting telescope,

and for comparison with the field of view in the eyepiece, the "up" direction of the chart should be oriented so that it points toward the north celestial pole.

Neptune passes close to four B.D. stars during its course in 1939. Data computed by Mr. John Phillips are listed below.

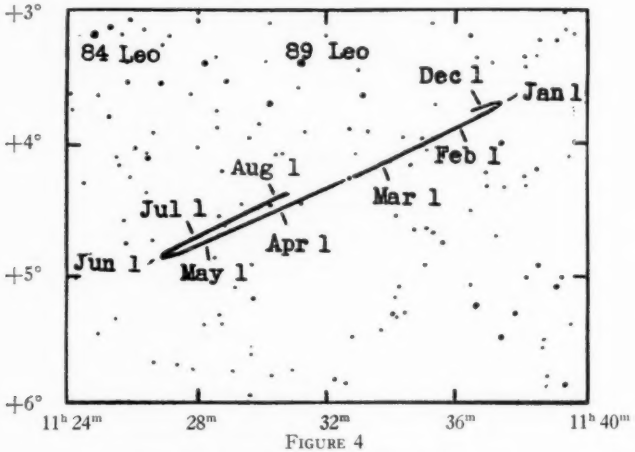


FIGURE 4

THE PATH OF NEPTUNE AMONG THE STARS, FROM DECEMBER, 1938, TO AUGUST, 1939.

Date of Close Approach		Star B.D.	B.D. Magn.	Minimum Angular Separation
	d h			
February	13 18.3	+4°2505	+8.7	2′ 32″
March	10 10.7	+4 2498	+9.0	1 14
March	25 0.0	+4 2496	+9.0	2 20
April	2 12.3	+4 2492	+8.8	2 34
July	30 9.0	+4 2492		0 15

Pluto. Pluto is in opposition with the sun January 22, and is located in the constellation Cancer, not far from the star λ Cancri. The position at the time of opposition is, $\alpha = 8^h\,14^m$, $\delta = +23°\,23'$. The stellar magnitude of Pluto is +15.0, so that a large telescope, probably one of at least 20 inches aperture, is needed for locating the planet by visual means. A chart showing the configuration of faint stars in the region of Pluto would be almost a necessity for positive identification of the planet. It does not seem worth while to prepare such a chart for POPULAR ASTRONOMY, since very few observers have access to a large instrument. Practically all observational research work on Pluto is done photographically.

Planet Notes for February, 1939

By R. S. ZUG

NOTE: Greenwich Civil Time is employed unless otherwise stated. To obtain Eastern Standard Time subtract 5 hours, Central Standard Time, 6 hours, etc. The planetary phenomena are described as they are to be seen from latitude 45° N. The data are taken chiefly from the *American Ephemeris and Nautical Almanac.*

Sun. The positions of the sun for February 1 and February 28, respectively, are: $\alpha = 20^h\,54^m.8$, $\delta = -17°\,24'.7$; $\alpha = 22^h\,40^m.5$, $\delta = -8°\,22'.9$. The sun is in the constellation Capricornus until February 16, when it enters Aquarius. Values for the equation of time are as follows:

Date 1939	Equation of Time (Mean - Apparent) m s	Date 1939	Equation of Time (Mean - Apparent) m s
Jan 31	+13 23	Feb. 16	+14 16
Feb. 4	+13 56	20	+13 59
8	+14 15	24	+13 31
12	+14 21	28	+12 53

Moon. Phenomena of the moon will occur as follows:

		h m
Full Moon	Feb 4	7 55
Last Quarter	11	4 12
New Moon	19	8 28
First Quarter	27	3 26
Perigee	4	0
Apogee	17	2

Mercury. Mercury is in superior conjunction with the sun February 19, 2^h. On February 26, 5^h, Mercury will be situated 25′ to the south of, and in conjunction with, Jupiter. However, both planets will probably be too close to the sun for observation.

Venus. This planet is now a brilliant morning star of about magnitude —3.9. Greatest western elongation (46° 56′) was reached January 30. On February 1, 51% of the apparent disk will be illuminated, this quantity increasing to 63% by February 28.

An occultation of the 7.6 magn. star, B.D. —17°4616, by Venus occurs January 17, according to the prediction of Mr. Arthur Burnet, appearing under "Occultations by Planets," in *The Handbook of the British Astronomical Association* for 1939. The occultation is visible in North America. This information was not at hand in time for inclusion in "Planet Notes" for January, 1939, but it is hoped that the copies of this issue will reach subscribers in time for the occultation. Circumstances of the occultation, as provided by Mr. Burnet, are as follows:

Geocentric conjunction in α	1939 Jan. 17 $13^h\,32^m.5$
α of star and planet	$16^h\,37^m\,45^s.90$
δ of star	—17° 56′ 24″.5
δ of Venus	—17° 56′ 27″.5

The illuminated phase at the time is 0.43, the disappearance taking place at the bright limb.

Place	——Immersion—— G.C.T. h m	Position Angle	——Emersion—— G.C.T. h m	Position Angle
Victoria, British Columbia	13 16	71°	13 39	307°
Lick (Mt. Hamilton, Calif.)	13 15	77	13 39	304
Flagstaff, Arizona	13 16	76	13 39	306
Denver, Colorado	13 17	72	13 40	307

Mars. Mars is a morning star during February, and moves rapidly eastward through Scorpio and into Ophiuchus. On February 11 and 12, Mars will be situated 5° north of Antares. On February 1 the angular diameter of Mars will be 5″.7, a value which increases to 6″.7 by the end of the month. The stellar magnitude

varies from +1.3 to +1.0 during the month. A conjunction with the moon occurs February 12, $12^h\ 31^m$, the moon passing 1° 40′ to the north of Mars.

Jupiter. Jupiter is an evening star, but will be lost in the sunset sky by the end of February, since the planet is rapidly approaching conjunction with the sun.

Saturn. Saturn is well situated for evening observation, just north of the celestial equator in Pisces. The stellar magnitude is +0.9 during February. The longer dimension of the ring system is now 37″.5 and the shorter 6″.6. The southern side of the ring system is now in view.

Uranus. Uranus is an evening object, in quadrature with the sun on February 3. The planet is situated about a degree northwest of the 5.5 magn. star, σ Arietis. The positions for February 1 and February 28 are, respectively:

$$\alpha = 2^h\ 46^m.1,\ \delta = +15°\ 40'.2;\ \alpha = 2^h\ 48^m.2,\ \delta = +15°\ 50'.4.$$

The magnitude of Uranus is +6.0 and its angular diameter 3″.5, so that it should be easily distinguishable with the most meager optical aid.

An occultation of Uranus occurs February 25, 9^h, invisible from the United States.

Neptune. A finding chart for Neptune appears in this issue under "Planetary Phenomena in 1939." On February 13, $18^h.3$, Neptune will be situated at a minimum angular distance of 2′ 32″ from the 9.5 magn. star, B.D. +4°2505.

Asteroid Notes

By HUGH S. RICE

The best asteroid for observation with small telescopes this month is the giant Ceres. It does not move much during this period, for it is turning back and assuming its direct motion about January 9. The position for January 8, evening, E.S.T., is about 2½° east of the star 38 Arietis. From this position it goes north and northeast to a position on February 9, 8½° northeast of μ Ceti. Its magnitude is about 8 during the interval. These directions will enable the observer to follow it, by plotting the places on a star chart.

It is planned to include considerably more extensive data than the above in the notes for the February issue.

Hayden Planetarium, New York, December 12, 1938.

Occultation Predictions

(Taken from the *American Ephemeris*)

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

Date 1939		Star	Mag.	Immersion Greenwich C.T.	Immersion *a*	Immersion *b*	Immersion Angle E from N	Emersion Greenwich C.T.	Emersion *a*	Emersion *b*	Emersion Angle E from N
				h m	m	m	°	h m	m	m	°
Occultations Visible in Longitude +72° 30′, Latitude +42° 30′.											
Feb.	2	74 B.Gem	6.2	1 25.2	—1.7	—1.7	140	2 23.0	—2.0	+1.8	236
	2	110 B.Gem	6.2	8 46.8	—0.6	+0.1	45	9 14.1	+0.7	—2.7	342
	5	14 Sex	6.3	9 31.0	—0.6	—1.7	123	10 30.6	—0.5	—1.6	284
	11	41 Lib	5.5	12 46.8	—1.8	—2.2	144	13 42.5	—1.3	0.0	231
	12	χ Oph	4.6	7 36.4	—1.1	+2.1	70	8 36.4	—0.6	—0.1	317
	15	173 B.Sgr	6.3	10 44.3	—1.0	+0.8	113	11 55.7	—1.7	+1.8	237
	22	62 Psc	6.1	22 47.1	—1.1	—0.7	76	23 57.9	—0.7	—0.5	244
	22	δ Psc	4.6	23 29.6	—0.7	+2.3	15	0 7.9	—0.6	—3.8	306
	27	85 H^1 Tau	6.0	0 2.7	—1.7	—2.0	120	1 9.2	—1.7	+0.6	233
	27	234 B.Tau	6.0	2 34.7	—1.1	—0.2	60	3 31.0	—0.2	—2.3	302
	28	71 Ori	5.2	21 22.7	—0.8	+3.0	46	22 14.6	—1.7	—1.1	314
Occultations Visible in Longitude +91° 0′, Latitude +40° 0′.											
Feb.	2	74 B.Gem	6.2	0 58.7	—1.6	—1.6	145	1 44.4	—1.2	+3.2	224
	2	110 B.Gem	6.2	8 35.6	—0.8	—0.8	77	9 26.8	+0.1	—2.0	313
	5	14 Sex	6.3	9 21.9	—0.8	—2.3	150	10 18.5	—1.4	—1.0	263
	11	41 Lib	5.5	12 20.3	..	..	160	13 7.2	..	..	225
	14	16 Sgr	6.0	11 46.7	—1.3	+0.5	115	13 4.2	—2.1	+1.4	245
	15	173 B.Sgr	6.3	10 34.9	+0.1	—0.3	138	11 19.8	—1.4	+3.0	218
	26	85 H^1 Tau	6.0	23 27.8	—2.4	—1.8	126	0 30.5	—1.9	+2.5	219
	27	234 B.Tau	6.0	2 9.6	—1.6	—0.4	80	3 24.3	—1.1	—1.5	278
	27	ε Tau	3.6	4 17.6	—1.2	+0.5	46	5 2.2	+0.1	—2.9	318
	28	353 B.Tau	6.4	0 46.1	..	..	20	1 14.7	..	..	340
Occultations Visible in Longitude +120° 0′, Latitude +36° 0′.											
Feb.	1	BD+19°1110	6.0	4 31.5	—2.1	+2.6	48	5 29.2	—1.9	—2.8	319
	1	57 Ori	5.9	5 53.7	—2.2	+0.8	67	7 1.6	—1.4	—2.3	308
	2	74 B.Gem	6.2	0 29.4	—0.6	—0.2	131	1 14.0	—0.1	+2.3	231
	2	110 B.Gem	6.2	8 9.7	—1.3	—1.8	123	9 17.7	—1.3	—1.0	270
	3	1 Cnc	6.0	3 33.6	..	..	35	4 1.6	..	..	346
	6	p^5 Leo	5.4	14 6.7	—1.2	0.0	58	14 43.0	—0.2	—3.1	348
	9	86 Vir	5.8	7 9.9	—0.7	+2.8	60	7 46.0	+0.3	—1.9	345
	26	26 B.Tau	6.4	5 13.9	—1.5	+2.0	30	5 50.8	+0.1	—3.9	323
	27	234 B.Tau	6.0	1 9.6	—2.2	+0.3	91	2 36.6	—2.2	+0.5	253
	27	ε Tau	3.6	3 31.6	—2.0	—0.2	81	4 51.6	—1.5	—1.3	276

Comet Notes

By G. VAN BIESBROECK

The year 1938 has been exceptionally quiet in regard to cometary activity. No new comets have been announced. The only object that has been under observation is Comet 1938*a* which was Periodic Comet 1927 VI (Gale) in its first return. It was followed for a little over a month into June and since then the absence of comets has been unusually long. Next month there is slight chance that Periodic Comet 1906 IV (Kopff) might be recovered. The orbit has been carefully worked out by F. Kepinski and the following ephemeris is probably quite precise:

1939	α h m	δ ° ′
Jan. 5	17 19.0	—24 43
13	17 43.2	24 36
21	18 7.6	24 15
29	18 31.1	—23 38

An independent prediction by the computing section of the British Astronomical Association differs very little from these figures. However, the conditions of visibility are very poor for northern observers. The comet is a morning object rising only an hour and a half before the sun, and being faint it can hardly be reached in that position. The conditions will improve in February but for southern observers only.

Williams Bay, Wisconsin, December 14, 1938

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

By this time it is assumed that most of the reports on the Perseid epoch have been received, so that the usual résumé of the observations is given. The moon being full almost exactly at the time of maximum, as a spectacle the shower was totally spoiled compared to a year without moonlight. Nevertheless, those who worked despite this handicap saw something worth while and their reports permit us to form a general idea of the richness of the stream. I am frankly disappointed that so many of our regular members did not work, whatever their reasons. Had it not been, therefore, for the generous coöperation of the general public, obtained through the press, our report would be pitifully inadequate.

By taking in the latter part of July, the Delta Aquarids are also included in the table. In the "Remarks" column, a indicates that the meteors were plotted regularly; b that more or less description is given beyond mere counts, (sometimes a very great deal); c that counts only were submitted; the numbers refer to how many observers took part at the station. As the factor, F, is of uncertain value below 0.5, I have thought it useless to give corrected rates. For the case of the moon full and sky clear, F = 0.4 on our scale. As many were this time hampered by clouds, haze, etc., in cases F drops to 0.2 or even 0.1. Corrected rates for such factors are obviously without value. Rates cannot be given on our scale when two or more coöperate in counting; this accounts for many blank spaces in the F column. The radiant points on the maps sent in by trained observers are rather few in number and have not yet been worked up. The A.M.S. is most grateful to those persons not members, who aided in this unfavorable return. They are cordially invited to join our ranks, as are any others interested in meteoric astronomy who may read this article. It is well to call attention to the fact that next August the Perseid maximum is as favorable as this was the opposite, for it falls midway between the phases last quarter and new of the moon.

Observer and Station	Aug.1938	Began	Ended	Min.	F	Met	Rate	R.
Ault, D. H., Norwood, Ohio	11	13:00	14:00	60		5	5.0	b
Beaudette, A. J., Flint, Mich.	12	15:15	16:15	60	0.4	13	13.0	c
Bosch, G. F., Scarsdale, N. Y.	11	11:00	14:00	180	0.2	9		3a
	12	10:00	13:00	180	0.4	30		3a
Bowers, Miss G., Washington, N. J.	11	12:00	14:00	120	0.2	30		2c
Brady, Mrs. L., Baldwin, Iowa	10	12:30	15:00	150	0.4	16	6.4	c
Brooks, W. J., Troy, N. Y.	11	11:30	13:30	120	0.2	10	5.0	b
	12	12:10	15:00	170	0.2	11	3.9	b
Diamant, L., New York City	11	10:30	11:30	60		7	7.0	c
Davis, Miss P., N. Calais, Vt.	12	12:00	13:40	100	0.4	40	24.0	c

Observer and Station	Aug.	1938	Began	Ended	Min.	F	Met	Rate	R.
Duggers, S., Williston, Fla.	11		10:45	13:00	135	0.4	16		2a
Eiseman, Miss M., Chevy Chase, Md.	12		8:15	9:30	75		7		?
Engle, Paul, Des Moines, Iowa	12		13:02	15:02	120	0.4	23	11.5	a
Sleeper, W., Booneville, Iowa	12		11:45	12:45	60	0.2	7	7.0	b
Dunivent, G., Des Moines, Iowa ...	11		10:31	11:31	60	0.4	9	9.0	b
	11		11:45	12:45	60	0.4	13	13.0	b
	11		14:45	15:45	60	0.4	13	13.0	b
Vaughn, F., Booneville, Iowa	11		12:59	13:59	60	0.4	28	28.0	b
	11		14:20	15:20	60	0.4	24	24.0	b
	11		10:30	11:30	60	0.4	14	14.0	b
Beamer, C., Booneville, Iowa	11		12:57	13:58	61	0.3	19	19.0	
Fagare, Miss M., Bernard, Iowa...	11		12:	13:30	90	0.4	5	3.3	c
Feldman, R. L., E. Falls Church, Va.	11		10:15	11:15	60		4	4.0	b
	12		8:15	10:00	60		2	2.0	b
	13		8:45	9:45	60		5	5.0	b
Fenner, W. I., N. Plainfield, N. J. ..	11		14:49	15:30	25		7		2c
Filancia, Miss C., Port Chester, N.Y.	12		11:40	13:40	120		14	7.0	c
Furtman, Mrs. A., Milwaukee, Wis.	11		10:00	11:00	60		11	11.0	c
	12		9:30	10:30	60		10	10.0	c
	13		9:45	10:45	60		15	15.0	c
Gamble, Miss D., Warren, Pa.	11		12:08	13:	52		4	4.6	c
	12		10:55	11:55	60		3	3.0	c
Bilbau, A. E., French Camp, Calif..	11		12:00	13:45	105		40	-	2
Gilbert, K., Pittsfield, Mass.	22		9:24	10:53	89	0.9	15	10.0	b
Glaze, B. C., San Antonio, Texas ..	13		10:58	16:59	241	0.4	35		2a
Gorson, R. O., Philadelphia, Pa. ...	11		12:39	15:00	125		32		2b
Graham, W. A., Morganton, N. C. .	12		11:05	11:35	30	0.4	9	18.0	c
Grayequist, H., Warren, Pa.	12		9:00	13:15	255	0.4	20	4.2	a
Laskaris, L, Warren, Pa.	12		8:45	13:58	313	0.4	35	6.7	a
Green, G., Pittsfield, Mass.	19		8:56	13:40	284	1.0	33	7.0	a
	22		9:30	13:52	262	0.8	42	9.6	a
Falce, W. J., Pittsfield, Pa.	11		8:28	11:42	194	0.3	8	2.5	c
	12		8:23	9:36	73	0.4	11	9.0	c
Gilbert, K., Pittsfield, Mass.	11		8:24	10:33	128	0.3	13	6.1	c
Victoreen, H. T., Pittsfield, Mass. ..	11		8:25	11:14	169	0.3	12	4.3	c
Habereck, J., Bayonne, N. J.	11		11:40	15:00	200		20	6.0	b
Hanusi, J., Lansing, Mich.	11		11:00	15:00	240		30	7.5	c
Hay, C. Charlotte, Mich.	11		13:00	14:00	60	0.4	17	17.0	c
Hoffman, C. D., Wheaton, Ill.	11		11:00	12:00	60	0.3	15	15.0	b
Isaac, Mrs. M., Glen Alpine, N. C..	11		10:30	13:15	165	0.1	7		b
Jardine, Mrs. J.T., Skyline Drive,Va.	20		9:30	10:	30		6	12.0	c
Jenkins, Miss C. M., Stateville, N. C.	12		10:12	11:45	93	0.3	8	5.2	c
Jenkins, Miss R. E., Fort Dodge, Ia.	11		14:30	15:45	60	0.1	24		7c
Jennings, W., Greensboro, N. C. ...	12		10:20	11:20	60		3	3.0	c
Johnson, O. B., Anderson, S. C.	10		9:00	12:00	180		9	3.0	c
	11		8:30	11:30	180		17	5.7	c
	12		9:00	12:00	180		11	3.7	c
Kaulfuss, J. E., State College, Pa. ..	12		11:59	13:20	33	0.4	10	18.2	b
Khan, M. A. R., Begumpet, India	July	28	13:00	15:00	90		29	19.3	b
		29	10:50	15:50	75		16	12.8	b
	Aug.	1	14:55	15:30	35		7	12.0	b
Kile, W. E., Gettysburg, Pa.	12		13:20	14:00	40	0.4	23	34.5	b
Leerman, J., Baltimore, Md.	14		8:45	9:45	60		8	8.0	c
McArthur, C., N. Quincy, Mass. ...	12		8:51	14:55	240	0.4	27	7.2	b
Horton, S. H., N. Quincy, Mass. ...	12		8:51	9:51	60	0.4	7	7.0	
Marino, Miss H., St. Bernard, La...	10		14:50	16:05	75	0.8	13	10.4	b
Mastell, R., Hibbing, Mich.	11		8:51	15:35	404		65	9.7	b
	12		10:09	12:00	111		14	7.6	b
Metcalf, Miss L., Cheverly, Md. ...	11		14:00	15:00	60		8		2c
Michael, R. E., Baltimore, Md.	11		12:00	16:05	244		36	8.8	b

Observer and Station	Aug.1938	Began	Ended	Min.	F	Met	Rate	R.
Morris, W. R.,	July 30	10:20	12:20	120	0.5	20	10.0	a
Constantine, Mich.	Aug. 11	11:05	14:55	230		42	11.0	a
	12	10:45	13:45	180		14	4.7	a
	19	10:30	13:05	155	1.0	28	10.8	a
Mosher, F. J., Clarkston, Wash. ...	11	11:00	13:00	120		13	6.5	c
Nicholsen, E., Pittsfield, Mass.	22	9:24	11:03	99	1.0	19	11.5	
Page, T. J., Stamford, Conn.	11	15:45	17:07	82		17	12.4	b
	12	13:27	16:49	202	0.3	16	4.7	b
	20	10:44	14:52	248		21	3.4	b
Euart, J., Providence, R. I.	12	12:40	14:30	110		16		2a
Pettey, Miss A., Providence, R. I...	12	12:15	14:15	120		13	6.5	c
Smiley, Mrs. C. H., Providence, R. I.	12	12:15	14:15	120		24	12.0	c
MacDonald, R., Providence, R. I....	12	12:15	14:00	135		34	15.1	c
Ebenhart, P., Providence, R. I.	12	12:15	14:15	120		44	22.0	c
Smiley, C. H., Providence, R. I. ...	12	12:15	14:15	120		19	9.5	c
Bilsborough, Miss, Providence, R. I.	12	12:15	14:15	120		18	9.0	c
Cooper, Miss E., Providence, R. I..	12	12:15	14:15	120		30	15.0	c
Pirsig, G., Blue Earth, Minn.	July 27	10:00	12:00	120	0.8	22	11.0	a
	Aug. 1	12:10	13:15	65	0.2	16		a
	11	10:15	11:15	60	1.0	17	17.0	a
Randall, N. C., Syracuse, N. Y. ...	11	10:25	11:25	60	0.2	8	8.0	c
Roach, S. P., San Antonio, Texas ..	13	11:20	14:55	215	0.5	9		
Rowe, H. A., Charleston, W. Va....	10	10:30	16:30		0.3	31		3a
	12	11:30	15:00		0.2	30		a
Schol, Miss D., and five others	11	9:53	16:45	412		65		a
Harriman Park, Pa.	12	9:15	16:15	420		64		a
Sember, M., Derby, Conn.	July 30	12:00	16:00	240	0.8	40	10.0	b
	Aug. 2	11:00	16:00	300	1.0	74	14.8	b
	3	10:30	16:00	330	0.8	48	8.7	b
	11	11:00	16:30	330	0.2	80	14.5	b
	12	9:30	14:00	270	0.3	67	14.9	b
Smith, C. W., Warren, Pa.	12	9:13	13:33	260	0.4	20	4.6	
Smith, F. R., Thiells, N. Y.	July 30	11:25	12:25	60		4	4.0	a
	Aug. 3	11:30	13:00	90		7	4.7	a
Sprecher, T. R., Ephrata, Pa.	11	11:45	13:15	90	0.2	10	6.7	b
Stone, W. R.,	July 26	10:30	14:30	240	1.0	15	3.7	a
Santa Barbara, Calif.	27	10:30	14:00	210	0.8	10	2.8	a
Sullens, J. L., West Plains, Mo. ...	24	10:43	13:43	180		59	19.7	b
	20	11:07	13:13	126		23	10.9	b
Traub, Miss L. E., N. Y. City	Aug. 11	11:45	12:30	45		7	9.3	b
Tuttle, Miss E. M., Paterson, N. J.	12	12:00	13:00	60		4	4.0	c
Vroney, F. P., Chicago, Ill.	11?					35		c
Welsh, W., New York City	11	13:00	17:17	257	0.2	34	7.9	c
	12	12:00	16:35	275	0.3	28	6.3	c
Whitney, B. S.,	July 18	9:30	10:31	61	1.0	5	4.9	a
Oklahoma City, Okla.	19	10:20	12:20	120	0.9	14	7.0	a
	27	9:15	10:45	90	0.3	8	5.3	a
Wills, W. H., Petersburg, Va.	Aug. 11	15:30	16:30	60		19	19.0	c
Young, Miss M. P., Johnstown, Pa.	12	10:52	12:12	80		18	13.5	b
Young, R. L., Baltimore, Md.	12	8:34	13:03	169		12	4.3	b
Zevy, A., New York City	10	14:15	15:15	60	0.2	20		2c
Nicholson, E., Pittsfield, Mass.	22	9:24	11:03	99	1.0	19	11.5	c
Gilbert, K., Pittsfield, Mass.	22	9:24	10:53	89	1.0	15	10.1	c

Flower Observatory, Upper Darby, Pennsylvania, 1938 December 15.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD,
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Meteoritic Dust and the Production of Metastable Nitrogen Molecules*

By JOSEPH KAPLAN,
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Abstract.—The part played by metastable nitrogen molecules and metastable nitrogen atoms in laboratory studies of auroral and night-sky spectra is reviewed. The indication, by recent discoveries, that surfaces play an important rôle in the production of metastable entities in the laboratory, is used as the basis for an hypothesis regarding the rôle of meteoritic dust in the upper atmosphere. It is suggested that the relatively large concentration of metastable molecules in the 40-70-mile region of the upper atmosphere can be ascribed to the presence there of meteoritic dust particles which act as surfaces for the production of these molecules. The luminescence of $ZnCO_3$ in the presence of active nitrogen suggests the possibility of a similar phenomenon with meteoritic material as the luminescing particles. Finally, the remarkable similarity between laboratory night-sky and auroral spectra and the natural spectra of the night sky and the aurorae is accounted for by the previously mentioned part played by meteoritic dust. Experimental verification of this hypothesis by Professor F. C. Leonard and the writer is proposed.

During the last few years problems of the earth's upper atmosphere have occupied the attention of an increasing number of investigators. The results of these investigations should be of great interest to a group of investigators interested in meteorites, since, like all other means of contact with the universe outside the earth, meteorites also must first traverse the earth's atmosphere before reaching the surface of the earth. Since space will not allow a complete review of the progress during even the last few years, I have selected my own work as the main part of this report, not only because I know it best but also because of interesting suggestions concerning the behavior of meteorites in the upper atmosphere which arise from these experiments.

In 1932 I observed for the first time in a laboratory source of gaseous nitrogen a group of bands due to N_2 and now referred to as the Vegard-Kaplan bands. Ordinarily the discovery of a new band system excites very little interest, but this system originates on an energy level of the molecule from which the molecule seldom departs with the emission of radiation. Such energy states are well known and important in astrophysics and are known as *metastable states.* Atoms which radiate from such states are responsible for many of the nebular lines and for such

*Read at the Sixth Annual Meeting of the Society, Richmond, Virginia, 1938 December 29 and 30.

well-known lines as the green auroral line. Thus the discovery of a similar radiation in molecular nitrogen excited considerable interest.

Members of the Vegard-Kaplan band-system were found to agree with some of the lines of the auroral spectrum. It was not until about two years after their discovery, however, that I observed the afterglow which was produced by extremely low current discharges in very pure nitrogen at low pressures and found that a remarkable increase in the intensity of these new bands relative to the normally strong bands of nitrogen took place. The equally remarkable production of the green auroral line when pure oxygen was added to these tubes led to the suggestion that the Vegard-Kaplan bands are present in the light of the night sky and that metastable nitrogen molecules play an important rôle in the phenomena of the earth's upper atmosphere.

In the course of the last year a new nitrogen afterglow phenomenon has been observed and studied. By preparing afterglow tubes at pressures of about 20 to 30 mm. in the manner which had led to the production of auroral and night-sky spectra in afterglows, an afterglow was observed which is of great interest not only to students of the upper atmosphere but also, as will be pointed out later, to students of meteoritics.

As in atomic oxygen, where the two lowest excited states lead, by transitions to the normal state and by a transition between them, to the emission of the well-known red and green auroral lines, so in atomic nitrogen one would expect similar transitions to occur. Undoubtedly many previous investigators had wondered why these lines had not been observed either in the sky or in the laboratory. The high-pressure afterglow gave the answer. In this afterglow there have been observed three interesting and probably significant radiations which had not been seen in similar lower-pressure glows. First and most interesting was the new atomic nitrogen line corresponding to one of the expected "auroral" transitions in atomic nitrogen. This line, predicted by I. S. Bowen to fall at $\lambda 3466.4 \pm 0.5$ Å., was found at $\lambda 3466.3 \pm 0.15$ Å. A short time later R. Bernard found it with almost the same relative intensity in the spectrum of a diffuse, low (high-pressure) aurora. Accompanying this line were the Vegard-Kaplan bands, again with an intensity as great as in the low-pressure, weak-discharge afterglow, and only recently the bands due to nitrogen and called the Goldstein-Kaplan bands, have been observed in these high-pressure glows. The part that these Goldstein-Kaplan bands play in upper-atmospheric phenomena is as yet a mystery. Indications are, however, that they should be interesting.

It is well known that recombination of atoms to form molecules requires a third body in general. In the laboratory studies of auroral and night-sky spectra, the walls of the discharge tube play this rôle in recombination processes. Evidence that this circumstance is true has been found recently in the increased intensity of the Vegard-Kaplan bands as the volume of the tube was diminished. Since these bands are radiated by metastable nitrogen molecules, it was at first expected that decreased tube size would result in a diminution of the Vegard-Kaplan-band intensity. That the opposite effect has been observed is certainly a real indication of the importance of *surfaces* for the production of metastable molecules.

Night-sky and auroral spectra show clear indications of a relatively large Vegard-Kaplan-band intensity at low altitudes, *i.e.*, at high pressures. The recently observed diffuse aurora of Bernard, which had a spectrum exactly like that of the high-pressure afterglow, is proof of this statement. This observation raises the question of the production of metastable molecules in the region of the upper

atmosphere between 40 and 70 miles. It is of interest to note in this connection that this is the region of maximum meteoric display and that, as a result of the consumption of meteorites, there is a steady production of dust particles in this region of the upper atmosphere. These dust particles can play two important rôles in the chemistry of this region. The primary rôle played by these particles is to provide the surfaces which are necessary for the promotion of atomic recombinations, the most important of which is the production of metastable nitrogen molecules. It is possible, however, that the energy of recombination, amounting to about 169,000 calories per mole, is liberated on the dust particle and produces a rise in temperature. This phenomenon has been observed in the recombination of atomic hydrogen on metallic surfaces such as tungsten. In fact, tungsten wires have been observed to rise to temperatures high enough to produce a brilliant glow, on account of the recombination of atomic hydrogen. The energy of this recombination is about 100,000 cal./mole as compared with the 169,000 cal./mole for nitrogen. Part of the continuous spectrum in the light of the night sky may originate in the luminescence of meteoritic dust particles produced by this recombination.

Another possible rôle played by meteoritic dust particles is suggested by a hitherto unpublished observation made about two years ago by me. C. P. zinc carbonate, $ZnCo_3$, had been introduced into an afterglow tube as a source of CO_2 for some proposed spectroscopic studies of the interaction between metastable nitrogen molecules and CO_2. A remarkable visible luminescence of the zinc carbonate was observed when the afterglow was being observed. This luminescence possessed a continuous spectrum and it outlasted the visible luminescence of the glowing nitrogen. The observations indicated very clearly that the luminescence was due to the bombardment of the zinc carbonate by the active nitrogen. The most remarkable aspect of this phenomenon is the failure of zinc carbonate to fluoresce or to phosphoresce under any other kind of excitation. It is quite possible that some of the light of the night sky producing a continuous spectrum originates in this type of solid luminescence, caused by the bombardment of the dust particles by active nitrogen.

One of the strangest features of auroral and night-sky research in the past ten years has been the accurate reproduction in my laboratory of auroral and night-sky spectra. The part played by meteoritic dust in promoting the production of metastable molecules may account for the success of the laboratory experiments in which the gas must of necessity be confined in small containers and in which surfaces must play a part similar to that played by the meteoritic dust particles.

Although the foregoing suggestions are entirely qualitative, it is of interest to note that these suggestions regarding the possible part played by meteorites in the chemistry of the upper atmosphere are amenable to experimental study. It is necessary simply to introduce meteoritic material into the nitrogen tubes in which the investigations concerning the upper atmosphere have been studied. I propose to undertake these investigations soon in collaboration with my colleague, Professor F. C. Leonard.

NOTES ADDED DECEMBER 12, 1938

1. It is interesting to add here that, in 1907, C. C. Trowbridge made the hypothesis that meteor trains are self-luminous gas clouds combined with meteoritic dust particles. The long duration of the meteor trains was accounted for on the hypothesis that they are a phosphorescence of the air. The papers of Trow-

bridge were not known to me at the time the preceding paper was written. It is therefore interesting that the phosphorescence of air was used by Trowbridge to account for meteor trains and that to account for the night-time phosphorescence of the upper atmosphere we make use of meteoritic dust. The study of the spectra of meteor trains should be investigated in an attempt to determine the character of the phosphorescence. Because of the short life of the train, this study would be extremely difficult, and yet, with the increased knowledge concerning other spectra of the upper atmosphere and various spectra of active nitrogen in the laboratory, it may be necessary to photograph only the strongest lines to obtain the key to this fascinating phenomenon.

2. From the average duration of the luminosity of a meteor train, it is possible to make interesting deductions concerning the light of the night sky and auroral displays. If we assume, with Trowbridge, that the luminosity of the meteor train is caused by a phosphorescence of the air, we can conclude that an afterglow can last as long as 40 minutes in the upper atmosphere. For a long time now it has been possible to produce perfect auroral and night-sky spectra in laboratory afterglows in nitrogen, as I reported earlier in this paper. In the absence of evidence as to the duration of an afterglow in the atmosphere (the lifetime in the laboratory is about 10 seconds), it has not appeared advisable to propose that auroral and night-sky radiations originate in the phosphorescence of the upper atmosphere. The long lifetime of meteor trains definitely suggests such an origin. It seems quite reasonable to propose that an auroral display consists of an initial activation followed by a long-lived afterglow. This is neither the time nor the place to develop these ideas, but we are impelled again to stress the importance of the field of meteoritics to the study of the upper atmosphere.

Literature on Tektites

Attention is called to an extensive paper by our Australian member, Dr. Charles Fenner of the University of Adelaide, published in and reprinted from the *Trans. Roy. Soc. So. Austr.*, 1938, **62** (2), 192-216, 2 pls., 3 figs., and entitled "Australites, Part III, A Contribution to the Problem of the Origin of Tektites." By no means the least useful and valuable feature of this paper is the apparently complete bibliography of tektite literature (pt. viii of the paper, pp. 210-16), comprising no fewer than 125 titles, dating from the year 1787 to the year 1938!

Committee Appointments

The following committee appointments have been made by the Executive Committee of the Council (the President and the Secretary of the Society). The first name under each committee is the name of the chairman of the committee.

Committee on Catalog: Mrs. Addie D. Nininger, W. F. Foshag, and L. J. Spencer.

Committee on Endowment: F. C. Leonard, L. F. Brady (*ex officio*), H. G. Fales, and D. M. Gillespie.

Committee on Membership: R. W. Webb (*ex officio*), H. A. Meyerhoff, O. E. Monnig, and H. H. Nininger (*ex officio*).

Committee on Terminology: L. La Paz, L. F. Brady, F. C. Leonard, and H. W. Nichols.

A Photomicrograph Showing Intensity Maxima in a Meteor Trail

By WALTER W. ZIMMERMAN *and* CHARLES R. HAMMOND,
Department of Astronomy, University of California, Los Angeles

The accompanying photomicrograph (Fig. 1) is of a trail made by a meteor which appeared 1938 November $19^d\ 21^h\ 15^m$ P.S.T., in the constellation Gemini. The trail crosses that of the fifth magnitude star, σ Geminorum, and is of interest in that it enables very close study of the intensity maxima or bursts along the path.

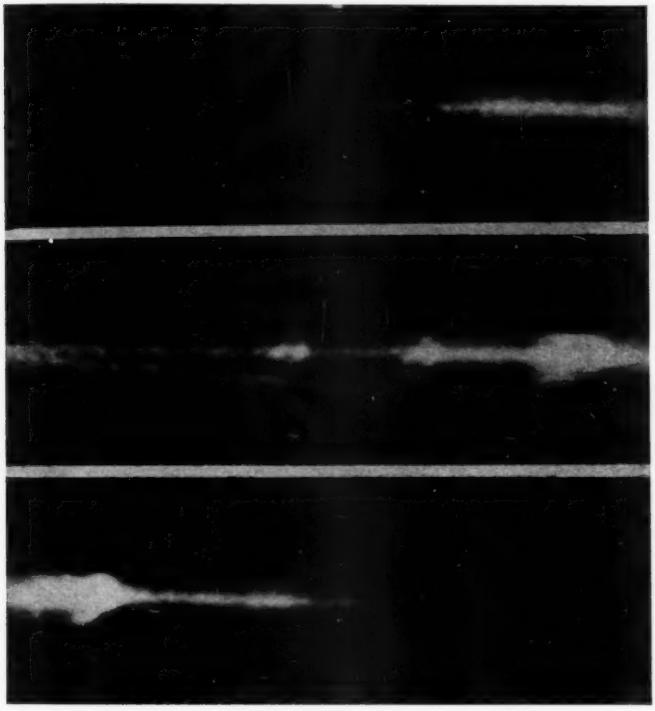

FIGURE 1
A PHOTOMICROGRAPH IN THREE SECTIONS, SHOWING THE INTENSITY MAXIMA IN THE METEOR TRAIL

Fig. 2 shows the meteor trail and the trails of the neighboring stars, while Fig. 1 is the photomicrograph of the trail itself in three sections, showing at least seven clearly defined bursts. The meteor camera employed was equipped with an *F:* 4.5 lens of 105-mm. focal length, stopped down to *F:* 5. The camera was loaded with Agfa "Superpan Press" roll film, which has extreme sensitivity combined with moderate-sized grain and is thus ideally suitable for this type of work. The point from which the original photograph was obtained is located on the Angeles Crest

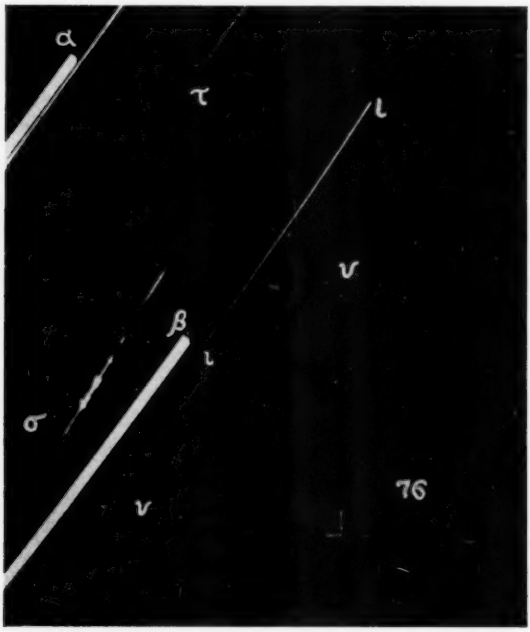

FIGURE 2
THE TRAIL OF THE METEOR OF 1938 NOVEMBER 19
AND STAR TRAILS IN GEMINI

Highway about three miles northwest of the Mount Wilson Observatory. The meteor was bluish white, of about the first magnitude, and remained visible for approximately a second.

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

The Russian Variable Star Bureau: In 1936 professional astronomers of the Soviet Union organized a committee for the purpose of planning a systematic investigation of hitherto unstudied or insufficiently studied variables. It was estimated that such objects would number about 2000; and the work was to be carried on chiefly by visual methods, with telescopes between five and ten inches in aperture. By January, 1938, more than 30,000 observations had been made, with the result that, of the stars so far investigated, the type of light variation had been determined for about 50 per cent. For the remainder, the incompleteness of the results may be partially attributed to the small light gathering power of the instruments used.

The sky was divided into 176 areas of approximately 225 square degrees each, and all stars attaining visual magnitude 12.0 at maximum were to be included. The purpose of this campaign resembles somewhat that of the recently established Milton Variable Star Bureau at Harvard which is investigating, from the more than fifty-year collection of Harvard plates, the periods, light variations, and types of variability of all stars which reach the tenth photographic magnitude, and for which definite information on these points is lacking. These two programs should fill a long felt need and eventually give us a vast amount of information on a large number of stars.

Light Variations of R Scuti: The irregular, bright variable star R Scuti, situated in the Milky Way, not far from the cluster M 11, has been an enigma to astronomers ever since its discovery by Pigott in 1795. During the past century it has been under almost constant scrutiny, in the early years by such experienced observers as Argelander, Schoenfeld, Schmidt, and others, and more recently by observers of variable star organizations. The data obtained during the past forty years may be considered as acceptably homogeneous and free from personal equation and color difficulties.

Various periods have been assigned, from two months for a single cycle, to 146 days for a so-called double cycle. For many years the star was classified as semi-regular, exemplifying many of the vagaries of RV Tauri stars; but more recent investigators have preferred to call it irregular, in spite of the underlying period of about 140 days which, with marked deviations, appears to persist throughout.

Dr. B. P. Gerasimovič concluded in 1927 that the question of period could apparently be considered as settled by assuming the presence of a secular change, from 139 days, at the end of the eighteenth century, to 147 days in 1921. Observations made since 1927, however, do not confirm this secular change (and this was not unexpected by Dr. Gerasomovič); in fact, the period since 1926 can be well satisfied by a value of 140 days.

Few attempts have been made heretofore to classify the different forms of light curves which R Scuti presents throughout the course of its variations. With the mass of observational material now available, however, averaging four to five observations per day, we have the means of making a tentative classification of the thirty-three cycles observed during the past dozen years. If this classification holds for a few years to come, it may be worth while to study the earlier data for possible confirmation of these types.

If one plots the observations—in this case five-day mean values taken from published material—for each 140 day cycle, vertically, instead of by the usual horizontal method, and separates the cycles from one another by this constant interval in time, the minima, or maxima, should fall under each other, if the assumed value of the period proves to be nearly correct and there are not too great variations in form of light curve. This has been done, and the data from 1926 to the present are shown in Figure 1. It is seen at a glance that not only is there a lack of uniformity in period, but, what is more pronounced, there are also decided variations in the form of the light curves.

The desired condition of minima falling in line held fairly well up to May, 1931, but since then the star has varied in a markedly irregular manner—from only small variations resembling small waves, for months at a time, to the entire absence of a definite minima at other times; pronounced maxima, with no sign of secondary maxima or minima, occur where deep minima were expected; and at

times there appears to be a reversal of deep and shallow minima.

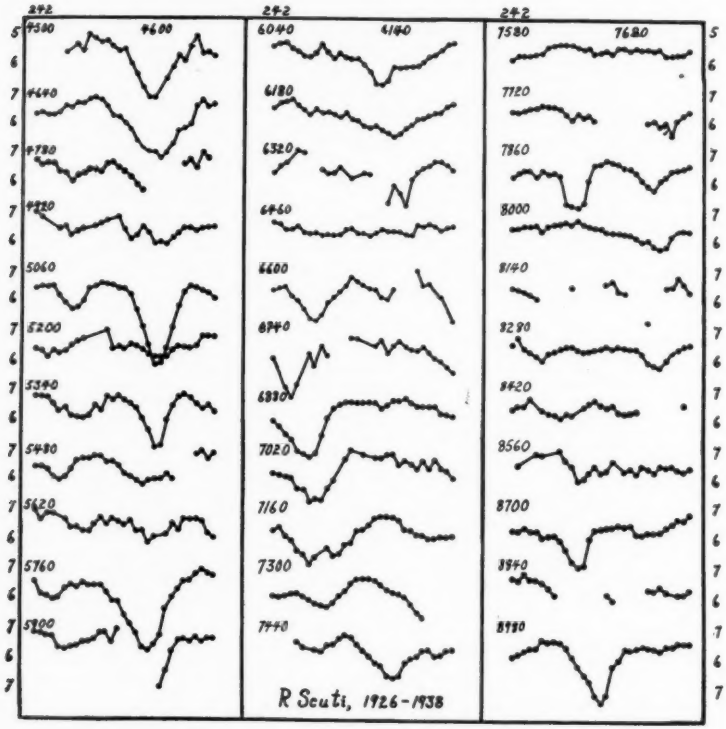

FIGURE 1

A preliminary classification of these light curves can be made into five distinct groups. A table showing the groups follows, the numbers under each heading representing the J.D. number placed at the left of the respective curves in the figure.

Type	I	II	III	IV	V
	6740	5620	4920	5480	4500
	6880	6460	5200	6040	4640
	7020	7580	6600	6180	4780
		7720	7160	6320	5060
		8000	7300	7440	5340
			7860	8420	5760
			8280		5900
			8560		8140
			8700		
			8840		
			8980		
Totals	3	5	11	6	8

Those curves which appear to belong to the same assigned class have been combined into mean light curves (see Figure 2). Class III predominates, with Class V next. Although it is to be noted that some curves of the same type seem to occur in succession, there is, however, no apparent uniformity regarding this sequence of similar types. Perhaps a later discussion of the best observations made during the whole of the nineteenth century might lead to more definite classification of light curves and also give material for studying possible laws of variation, both in curves and period.

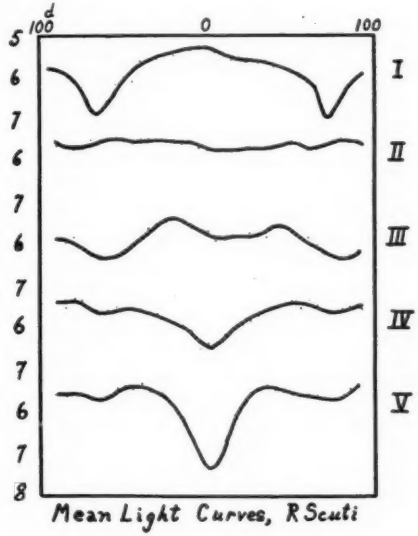

FIGURE 2

This interesting and highly important variable is by no means to be considered as sufficiently observed, but instead it should be even more carefully followed, and by photo-electric means, if possible, especially during times when the small wave conditions prevail.

Minima of β Persei (Algol): In view of the apparent lack of agreement in the predicted times of minima of Algol, as published in recent years, the following determination of a minimum observed visually by Dr. S. Gaposchkin is timely and would appear to give a satisfactory epoch upon which to base predicted minima, at least for the present season. The heliocentric time of minimum of the star as observed by him on December 4 was $9^h\,17^m$ (E.S.T. from Noon) or J.D. 2429237.595, and he believes it to be correct to within two minutes. The predicted time of minimum for this same date, computed from the formula given in Schneller's Catalogue, is 1938, December 4, $9^h\,11^m.4$ (E.S.T. from Noon), which indicates that the observed minimum occurred only a few minutes later than the computed value.

An ephemeris, based upon Gaposchkin's determination, follows, with times of minima referred to the 75th Meridian (E.S.T.):

1939	E.S.T.	1939	E.S.T.
Jan. 14	12:42 a.m.	Mar. 3	6:33 p.m.
16	9:31 p.m.	20	11:27 p.m.
19	6:20 p.m.	23	8:16 p.m.
Feb. 3	2:24 a.m.	26	5:05 p.m.
5	11:13 p.m.	Apr. 10	1:09 a.m.
8	8:02 p.m.	12	9:58 p.m.
11	4:51 p.m.	15	6:47 p.m.
26	12:56 a.m.		
28	9:44 p.m.		

The duration of minimum phase of this interesting, naked-eye eclipsing variable is approximately ten hours. Observations made for an hour before and after minimum should have the greatest value in determining the items of minima. When Algol is at its faintest phase it closely resembles ρ Persei in visual brightness.

Maxima of Long-Period Variables, 1939: Listed herewith are the dates during 1939 on which some of the brighter, well-known long-period variables will be at maximum. They are taken from the 1939 list of predicted dates of maxima and minima as published in a recent A.A.V.S.O. Bulletin. The magnitudes assigned the maximum phase are mean values only, and the actual observed magnitudes may differ by one or more magnitudes.

Variable	Designation	Date of Maximum	Maximum Magnitude
o Ceti	021403	Aug. 22	3.4
R Trianguli	023133	July 18	6.0
R Horologii	025050	Jan. 14	6.4
U Orionis	054920a	Jan. 14	6.0
R Carinae	092962	Mar. 13	4.4
R Leonis	094211	Sept. 15	5.9
S Carinae	100661	May 7	5.3
" "	"	Oct. 3	...
R Virginis	123307	Feb. 24	6.9
" "	"	July 19	...
R Centauri	140959	Aug. 9	6.0
R Bootis	143227	Mar. 10	7.1
" "	"	Oct. 18	...
S Cor. Bor.	151731	Sept. 26	7.0
R Serpentis	154615	Oct. 17	6.9
RS Scorpii	164844	Mar. 28	6.6
RR Scorpii	165030a	Sept. 3	6.0
R Aquilae	190108	Mar. 11	6.0
R Cygni	193449	Dec. 18	7.4
χ Cygni	194632	Aug. 11	5.1
RR Sagittarii	194929	May 17	6.6
T Cephei	210868	Sept. 11	5.0
R Aquarii	233815	Dec. 22	6.4
R Cassiopeiae	235350	June 21	7.1

Observers and Observations during November, 1938

Observer	Var.	Est.	Observer	Var.	Est.
Albrecht	10	10	Bouton	65	86
Ancarani	14	17	Buckstaff	12	37
Baldwin	111	203	Callum	85	118
Ball, A. R.	24	55	Cameron	8	8
Ball, J.	15	25	Christman	10	11
Beloit College	16	25	Cousins	25	81
Blunck	13	23	Mrs. Dafter	10	20

Observer	Var.	Est.	Observer	Var.	Est.
Davis	8	15	Murphy	20	21
Diedrich	10	12	Neale	2	2
Economou	6	19	Needham	56	92
Escalante	96	167	Parker	23	36
Evans	25	25	Peterson	1	4
Fairbanks	16	26	Peltier	197	281
Ferguson	3	6	Prinslow	9	9
Fernald	30	175	Purdy	9	15
Franklin	45	100	Mrs. Rademacher	3	3
Gregory	108	202	Recinsky	15	59
Halbach	63	63	Reynolds	10	31
Hamilton	20	37	Rosebrugh	20	85
Harris	11	11	de Roy	19	90
Hassler	7	7	Russell	29	55
Hartmann	178	364	Ryder	13	13
Herbig	154	572	Seely	20	53
Hiett	21	87	Shafer	4	9
Hildom	39	58	Siebel	2	2
Mrs. Holmes	3	4	Sill	60	60
Holt	74	104	Smith, F. P.	35	57
Howarth	7	8	Smith, F. W.	3	6
Irland	16	16	Smith, J. R.	22	22
Jones	77	295	Smith, L.	15	15
Kanda	2	15	Starr	6	6
Mrs. Kearons	57	100	Topham	17	21
Kelly	10	12	Treadwell	11	11
Kirkpatrick	23	95	Webb	18	24
Koons	83	112	Weber	16	23
Loreta	168	589	Williams	10	23
Maupomé	19	20	Woods	23	69
McLeod	38	89	Yamasaki	33	34
Meek	56	580			
Millard	25	29	Total observations		5987
Monnig	21	33			

December 13, 1938

Notes from Amateurs

The New Haven Amateur Astronomical Society

The meeting of the New Haven Amateur Astronomical Society, held on December 3, was, as usual, a well-attended and instructive meeting.

An Aurora Observing Group was organized with Mr. Glowacki as chairman and elaborate plans have been worked out for a systematic and thorough study, observation, and photographing of the aurora and more will undoubtedly be heard from this group later.

Plans were formulated for the Second Anniversary of the Society to be observed January 7.

The speaker of the evening was Dr. Stearns of the Van Vleck Observatory in Middletown who gave a very interesting talk on "Comets." He stated that two of the most popular astronomical phenomena were comets and the total eclipse of the sun, owing largely to the infrequency of their appearing. He referred to the newspaper publicity that was given the 1925 eclipse and the 1910 appearance of Halley's comet. He cited a number of instances of comet appearances in early times which

the people of the time believed were evil omens and foretold evil events and disaster to rulers and nations. The early idea of comets was that they were traveling within the earth's atmosphere but some claimed they came from outside our atmosphere. It was evident that they could not be planets and certainly could not be stars, so, obviously, they must be something else, and the paramount question was what and where were they. Tycho Brahe showed comets had no parallax and therefore they must be a great distance away and certainly not in the earth's atmosphere. Kepler decided that they moved in straight lines and were formed of gathered celestial matter. Newton proved that comets must move in orbits around the sun. Halley computed the orbits of 29 comets, many of previous years visibility, and was the first to predict the return of comets. He predicted the return of the 1682 comet in 1759. On Christmas, 1758, this comet was observed by an amateur within one month of the time Halley had predicted, and has reappeared approximately every 77 years since, the last appearance being 1910.

The bright comet of 1882 was a beautiful spectacle and in attempting to photograph it in its splendor the astronomers were surprised to note the number of stars in the background on the developed plate and the idea of photographing stars for records and measuring purposes was born. Dr. Stearns stated that the average comet was about the size of the sun, and the density of the head comparable to 12 marbles scattered in a cubic mile, comets do not disturb or their tails affect planets, but planets seriously affect the orbits of comets.

He described the discovery of the Stearns Comet (named after himself) which he discovered in 1927 by noticing a faint stray nebulous patch while using the 21-inch refractor at the Van Vleck Observatory. He stated that he observed it for several nights, carefully checked available records and catalogues, and ascertained that there were no nebulae in that region. He observed its definite motion from day to day and was firmly convinced that he had discovered a new comet. Stearns Comet was observed continuously for four years which is an exceptionally long time for continual observations.

Dr. Stearns during his most interesting talk on comets showed numerous slides to illustrate and explain many of his statements.

December 15, 1938. F. R. BURNHAM, *Secretary.*

Communications and Comments

Under this heading we shall publish from time to time such material as does not properly fall under any of the established headings of this journal. Here, too, may be found, when occasion arises, articles which the editors may not be willing to give sanction to but which, nevertheless, may be provocative of thought along new lines.

On the Red-Shift of Light

The papers published in POPULAR ASTRONOMY under the heading Communications and Comments are very interesting, discussing new theories and hypotheses.

In the August-September, 1937, number a new theory of light is given by Ben Hur Wilson. Just what is wrong with this theory I should not say, as the wrongness may be with me, but if gravitation acts on light at all, it seems to me that it must act in the same way whether the center of gravitation be that of a galaxy or that of a star like the companion of Sirius. In other words, if light slowed by a strong gravitational field shows a shift toward the red end of the spectrum, then light accelerated by gravitation should show a shift toward the violet end.

If light is affected by gravitation, as it seems to be, then light leaving a galaxy must be slowed on escaping into space. On entering the gravitational field of another galaxy the same light must be accelerated. Now, if the two galaxies in question are of equal masses, the speed of light should apparently be the same on entering galaxy No. 2 as on leaving galaxy No. 1, providing no other factors were involved than the gravitational masses and the distances between them.

The galaxies may, of course, differ in mass, but would it not be just as incredible to suppose that the galaxies increased in mass in proportion to the distance from the earth, as to believe that their speed of recession depends on the same distance? It would be more incredible to believe in the mass increase, as the "Expanding Universe" may at least be explained by supposing that all the matter in the universe once upon a time was consolidated in one place.

The outer galaxies are far away and very little obscuring matter in space would be required to account for the red-shift in their spectra. We now know that obscuring matter is present in the plane of our own galaxy, but how about the space between the galaxies? Would it be improper to think that there is no such thing as a perfect vacuum in the universe?

We are just learning to know the way light acts inside our own galaxy. And this action is such that it will be very difficult to prove Ben Hur Wilson's Hypothesis of Accelerating Light Corpuscles by the method suggested, by light coming to earth from two equally distant galaxies and entering our own galaxy at the plane and at right angles to it, or reaching earth by way of the long and short axis of the plane respectively. The possibility of this proof seems very slight when the obscuring matter in the plane of our galaxy is taken into account, for just how much this obscuring matter affects light is still under discussion. And when that question is settled comes the greater question of obscuring matter in outer space.

Kreftings gt. 5, Hønefoss, Norway. HANS A. ERIKSEN.

General Notes

As the several copies of this issue will reach their various destinations on or near the beginning of the New Year, it is the wish of all who are at the sending end that these copies may convey to all those at the receiving end most cordial greetings and hearty good wishes.

Dr. H. Spencer Jones, Astronomer Royal, will deliver the fourteenth annual Norman Lockyer lecture under the auspices of the British Association at the Goldsmiths' Hall, London, E. C. 2, on Tuesday, December 6, at 4:00 P.M. The subject of the lecture will be "The Atmospheres of the Planets." (*Nature*, November 19, 1938.)

Recent Observations on β 648 Requested

Dr. Aitken has supplied the writer with recent measures (up to and including 1935) of the binary system β 648, which he intends to use to improve the elements of the last orbit published, that by Miss Gushee in 1925 (POPULAR ASTRONOMY, Vol. XXXIII, May, 1925). From the observations it appears that the orbital pair will complete a revolution in 1938, so it is hoped that observers who have obtained additional measures will communicate them to the undersigned.

108 Laidley Street, San Francisco, California. HENRY RAPHAEL.

Change from 3″ to 1″.5 in the Reduction of Occultations observed in 1939

The following annual mean values for the observed correction to the moon's tabular mean longitude have been obtained from a provisional discussion of disappearances at the dark limb of stars contained in Hammond's Zodiacal Catalogue, and reduced with Hammond's positions.

1936.5	$+2''.53 \pm 0''.10$
1937.5	$+2.12 \pm 0.06$
1938.5	$+1.86 \pm 0.27$

The results indicate that the diminution of the correction to the lunar tables continues.

Beginning with the first lunation of 1939 (New Moon of 1938, December 21) it is requested that reductions of occultations be made with the correction $+1''.5$ to the moon's tabular mean longitude. This corresponds to the correction $+0^h.00076$ in time.

The large change from the published value 1935.5, $+3''.41$ (*A.J.* 1076) to the provisional result for 1936.5 can be accounted for by the difference in equinox of numerous star positions included in the discussion for 1935 and that of Hammond's Catalogue which is now used as standard.

DIRK BROUWER, *Chairman*,
Sub-Commission on Occultations, International Astronomical Union.
Yale University Observatory.

Naked-Eye Observations of the Lunar Eclipse of November 7, 1938

Sixteen students in the elementary classes in astronomy at Smith College observed the lunar eclipse on November 7. Besides making drawings to show the progress of the shadow across the disc and studying the surface of the moon through field glasses and small telescopes, they estimated with the unaided eye the times of third and fourth contact. The times were all read from the same clock which had no second hand but which had been set to read the correct Eastern Standard Time within 5 or 6 seconds. The range of estimated times of third contact was 2.2 minutes; and of fourth contact, 3.1 minutes. The average observed time of third contact was $6^h\,7^m.1$, and of fourth contact, $7^h\,11^m.8$.

LOIS T. SLOCUM.
Smith College Observatory, Northampton, Massachusetts.

Book Reviews

Atoms, Rocks, and Galaxies, A Survey in Physical Science, by John S. Allen and others. (Harper and Brothers, New York and London, Publishers. Price $3.00.)

Professor Allen and his associates are to be congratulated on presenting an excellent survey of the physical sciences. Working on an extremely broad scale the authors have successfully avoided any hint of the customary criticism of similar texts, namely, "skimming."

Beginning with a discussion of the solar system and dealing with geology, meteorology, oceanography, physics, chemistry, and astronomy, each of the contributors has fortunately been able to give a broad description of these fields in relation to the other physical sciences, and, at the same time, to include the basic information necessary to an understanding of his branch of science.

The geological division is an ably written evolutionary portrayal of the formation of the earth. From the beginning the author has continued to develop a good understanding of the processes of deposition and erosion which are responsible for the geological landscapes of today. This section also contributes an excellent description of life from early forms through the pre-history period of man.

In contrast to the previous section the author of the material dealing with the atmosphere has preferred to describe the principles of meteorology without carrying them to a logical conclusion. The theory of air mass analysis is not completely developed and the author has continued the out-moded idea of a "temperate zone." It seems likely that the inclusion of some recognized climatic system such as the Köppen or Thornthwaite classifications would have carried this portion of the work to a sound conclusion in much the same way as the development of the surface configuration was accomplished in the geological portion of the text.

The chapters on physical chemistry appear to be clearly and concisely presented. Much of the material under consideration is clarified by a judicious selection of diagrams which leave little to be desired.

After completing the world and those forces which are active in formulating man's adjustment to his environment, the final chapters are devoted to relating the earth to its proper position in the universe. No one can complete the reading of this book without a clearer understanding of man's small rôle and insignificant position in the universe as a whole. The book is unhesitatingly recommended as one of the best in the field of orientation texts.

Carleton College. LEONARD S. WILSON, Instructor in Geography.

Die Wunder des Himmels, by J. J. von Littrow, 574 pp., 277 illustrations. Tenth edition revised by F. Becker. (Ferd. Dümmler, Bonn and Berlin. Price 6.60 marks.)

In 1834 there appeared the first edition of Littrow's "Wunder des Himmels," a popular treatise on astronomy. It was very well received and the author prepared two later editions during his lifetime. The demand for the book continued and the author's son, Karl von Littrow, prepared the later editions up to the eighth. A ninth edition (1910) was prepared by Dr. Paul Guthnick and this tenth edition was revised and largely rewritten by Dr. F. Becker of the Bonn Observatory.

The present edition is a very readable popuiar account of the field of astronomy. No attempt has been made to "jazz" the subject. The many illustrations have been well chosen. The publishers are to be congratulated that they did not yield to the prevailing German custom of putting a high price on the book. The new edition of Littrow can be recommended to any who can read German.

E. A. F.

Stars and Constellations, by Clarence A. Holden. (Newspaper Information Service, Inc., 1013 Thirteenth Street, N. W., Washington, D. C.)

This is a pocket-sized handbook consisting principally of an alphabetical arrangement of the constellations, with the principal objects in each briefly described. It is useful for quick reference when not a great deal of detail is required. It is number 180 in a series of similar "service books," and may be purchased for ten cents.

POPULAR ASTRONOMY

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